THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

EXECUTIVE SUMMARY

ROBOTICS IN SHIPBUILDING

WORKSHOP

U.S. DEPARTMENT OF COMMERCE
Maritime Administration
in cooperation with
Todd Pacific Shipyards Corporation

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SHIP PRODUCIBILITY RESEARCH PROGRAM

EXECUTIVE SUMMARY
ROBOTICS IN SHIPBUILDING
WORKSHOP

PREPARED BY:

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EXECUTIVE SUMMARY
OF
PROCEEDINGS FOR
ROBOTICS IN SHIPBUILDING
WORKSHOP

1. HISTORY OF THE WORKSHOP

Following discussions with members of-the Maritime Administrator's office of Advanced Ship Development, Todd Pacific Shipyards Los Angeles Division (TPLA) felt that shipyard interest in the field of Robotics existed, but that an informational void needed to be satisfied before they can adequately deal with this new technology.

To initiate the shipbuilding industry into the field of robotics and to assess their needs which could potentially be met by robots, the Maritime Administration, in conjunction with TPLA held a three-day workshop hosted by TPLA in Long Beach, California on October 14 through October 16, 1981. Attendance included 18 Shipyards, 7 Universities, 4 Robot Manufacturers, 15 Shipyard Suppliers, MARAD, NAVMAT, NAVSEA and the Office of the Assistant Secretary of the Navy (MRA&L).

The following is a report of this workshop in which a number of problems were identified, some preliminary projects for cooperative development were specified, and the industry direction for developing a program was established.

2. WORKSHOP PURPOSE AND APPROACH

The purpose of the workshop was to bring together a representative mix of industry experts, government representatives and educators to develop an understanding of robotics, ascertain the degree of common problems within the industry associated with potential robotics applications and to make recommendations as to what cooperative action might be taken to resolve these problems.

The first two morning sessions were devoted to presentations by experts in the various phases of robotics to establish a common base for understanding the current state-of-the-art of robotics. Afternoon sessions were divided into two phases. The first consisted of roundtable discussions by all attendees to gain an overview of shipyard requirements for improving productivity and/or reducing the number of people doing undesirable tasks. The second was to form three discussion groups to establish the state-of-the-art in their respective areas, identify economic problems, and recommend such action as would possibly satisfy the shipyard requirements through the application of robotics. These groups were:

Welding and Assembly

Surface Preparation/Coating & Material Handling

Facilities/Industrial-Manufacturing Engineering, CAD/CAM Interface

And Other Potential Applications.

3. WORKSHOP CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The collective efforts of participants in the Workshop through discussions in the general sessions and panels developed a number of significant conclusions.

1. While the application of robotics technology to the shipbuilding industry cannot be a panacea, it can be an excellent tool for improving productivity if we pick the applicants carefully and utilize them properly.
2. In order to apply robotics technology:, a program is needed and must be developed by the shipbuilding industry, working with robotics manufacturers and educational institutions and supported by MARAD and the Navy.
3. In order to best meet the requirements of all participants in a robotics program, we need to develop a "road map" that will tell us how to:
   a. Best transfer the technology now existing,
   b. Develop and apply new technology, and
   c. Target applications to the high cost drivers-in the industry.
4. Time is of essence in order to allow sufficient lead time for budgeting of support funding by MARAD and the Navy.

<u>Recommendations</u>

Review of the roundtable sessions, panel recommendations and the overall conclusions by the participants result in the following recommendations:

1. Increased promotion of robotics technology and its application to the shipbuilding industry.
2. Develop a program in which the shipbuilding industry takes the lead and works with robotics manufacturers and educational institutions to apply robotics technology to the industry.

3. Establish a Shipbuilding Robotics panel under the Ship Production Committee of the Society of Naval Architects and Marine Engineers (SNAME) to take action on these recommendations and continue the work of this workshop including responsibilities to act for the industry in coordinating a cooperative technical program with the Maritime Administration and the Navy and:

   a. Develop a "roadmap" for transferring existing and developing/ applying new robotics technology;
   b. Establish a consensus priority list of high cost driver areas for target applications of robotics technology;
   c. Solicit and review proposed robotics research projects which address problem areas;
   d. Coordinate the efforts of other SNAME panels proposing robotics applications;
   e. Maintain an up-to-date awareness of robotics technology as it applies to shipbuilding technology;
   f. Provide continuing program guidance and overview;
   g. Publish and disseminate research results to the industry;
   h. Maintain a flexible program with redirection capability to address new problems/technology as they arise; and
   i. Schedule periodic technical meetings for the shipbuilding industry.

NSRP-SPC-SP10

ROBOTICS IN SHIPBUILDING
WORKSHOP

OCTOBER 13 - 16, 1981

LONG BEACH, CALIFORNIA

PROCEEDINGS FOR

ROBOTICS IN SHIPBUILDING

WORKSHOP

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SECTION I

SHIP PRODUCIBILITY

RESEARCH PROGRAM

1.1 History of the Ship Producibility Research Program

Following enactment of the Merchant Marine Act, 1970, the National Shipbuilding Research Program was established by the Maritime Administration. Provisions of this legislation charged the Secretary of Commerce with the responsibility to "collaborate with . . . .shipbuilders in developing plans for the construction of vessels" (Section 212 (c)). The shipbuilding industry direction for program is provided by the Ship Production Cormmittee (SPC) of the Society of Naval Architects and Engineers (SNAME). This program is responsible for the cooperative industry program to develop improved technical information and procedures for use by U.S. shipyards in reducing the cost and time for building ships. Recently, the use of robotics has been touched upon by several of the SNAME/SPC Panels resulting in some sparodic moves to investigate specific applications. As one of the participating shipyards, Todd Pacific, Los Angeles Divsion (TPLA), perceived the need for a workshop to fill the void existing in the industry regarding robotics. Discussions with representatives of the Maritime Adminstration, Naval Material Command and various shipyards confirmed this need.

To initiate the shipbuilding industry into the field of robotics and to assess their needs which could potentially be met by robots, the Maritime Administration, in conjunction with TPLA held a three-day workshop hosted by TPLA in Long Beach, California on October 14 through Ocotber 16, 1981. Attendance included 18 Shipyards, 7 Universities, 4 Robot Manufacturers, 15 Shipyard Suppliers, Marad NAVMAT, NAVSEA and the office of the Assistant Secretary of the Navy (MRA&L).

The following is a report of this workshop in which a number of problems were identified, some preliminary projects for cooperative development were specified, and the industry direction for developing a program was established.

1.2 Workshop Purpose and Approach

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The first two morning sessions were devoted to presentations by experts in the various phases of robotics to establish a common base for understanding the current state-of-the-art of robotics. Afternoon sessions were divided into two phases. The first consisted of roundtable discussions by all attendees to gain an overview of shipyard requirements for improving productivity and/or reducing the number of people doing undesirable tasks. The second was to form three discussion groups to establish the state-of-the-art in their respective areas, identify economic problems, and recommend such action as would possibly satisfy the shipyard requirements through the application of robotics.

These groups were:

Welding and Assembly

Surface Preparation/Coating & Material Handling

Facilities/Industrial-Manufacturing Engineering, CAD/CAM Interface And Other Potential Applications.

SECTION II

ROUNDTABLE SESSION

SUMMARY

2.1 <u>Discussion</u>

The roundtable sessions produced many questions and much discussion verifying the need for the workshop. The lack of exposure of shipyard personnel to robotics appeared to cause the participants to explore specific information on robots and the adoption of existing robots to applications under study rather than developing an overview of shipyard requirements for improving productivity as anticipated in the agenda. As the sessions progressed, questions were raised and answered, educational and constructive comments were made, and the foundations were laid for the panels to direct their efforts to specific results and for the conclusions and recommendations contained herein. Some of the more significant items covered are summarized below.

2.2 <u>Questions and Answers</u>

2.2.1 <u>Question</u>: We all know the Robotics Institute Definition, but just what is a robot; where does it cease being an automatic machine and become a robot?

<u>Answer</u>: A robot is basically a substitute for the human arm. It

1. Can use tools;
2. Can pick, place and carry materials;
3. Is controlled by a brain and senses;
4. Has limited variables as compared to the human but is much stronger in lifting/staying capacity;
5. Can do several different tasks whereas the automatic machine can do only one (e.g. machining, burning, etc.).

2.2.2 Question: What are some of the weakness of today's robots?

Answer: 1. They cannot completely duplicate the human arm, (e.g. it cannot throw a ball).

2. They are generally not accurate under load on repetitive operations, therefore must be calibrated frequently. (This was disputed by one manufacturer).

3. They are energy intensive, therefore must be much more productive than previous methods to be justified.

4. They tend to accumulate error.

5. They are sensitive to undesirable environments.

6. They lack closed loop feedback systems (such as eye, touch, etc.).

2.2.3 Question: Do we have a serious productivity problem in the U.S.?

Answer: Definetly yes but

1. We must want to achieve productivity.

2. We must walk before we run and

3. We must achieve it or we will be beaten out by foreign yards that are continuing their improvements,

2.2.4 Question: What tools are there to aid us in improving productivity?

Answer: 1. People (in the U.S.) tend to look for magical solutions; there are none.

2. We appear to wait for super sophistication (i.e. the perfected machine); we can't afford that any longer.

3. There are tools of existing technology in other industries; we should transfer some of the technology.

4. Today's robotics technology, along with that which we can help develop, will provide part of the solution.

2.3 Digest of Comments

1. We must address simple problems existing today; not what we could do with good technology if we had it.
2. We must improve productivity - determine the application of robots - on the basis of what we need to do to get there.
3. Our challenge: to start from the beginning as there is not enough history to know what we can do with robots.
4. Limited experience with some existing robots has indicated only 60% accuracy reflecting the need for more vendor development, we should test them further, to verify this performance accuracy.
5. Robot manufacturers should work with shipbuilders, starting in our fabrication shop.
6. We (Shipbuilders) need to scope our problems (as they apply to robotic applications) and establish the economic feasibility of robots as solutions.
7. Evaluation should start by choosing an application (known technology) that won’t fail, it will have a higher payoff and can be kept under control.
8. We must overcome the inertia of the past (within the shipbuilding industry) and look realistically at the potential benefits that can be derived from the application of robotics.
9. One of the things we need most is knowledge.
10. Robots are here to stay, therefore we need to learn the system, the tool and the impact it will have on the entire manufacturing system.
11. In applying robotics technology we will make mistakes but we can’t let them stop progress for, as with the introduction of any new tool, we will use it for what we want and will change our way of thinking about the product.

12. The Japanese are using robotics because they are committed to improving productivity; if we are to regain/remain competitive we must also commit to the transfer of existing and adoption of new (robotics) technology.

13. Regarding welding applications:

    a. The robot must demonstrate its ability to equal the quality a manual welding. (This is part of the subject of the SNAME project now being performed by TPLA).

    b. Robots have already demonstrated their ability to weld with quality equal to manual and to meet military specifications; the problem is access to the part by the robot - not its ability to weld.

14. No matter what process a robot is adapted to, its ability to do the job must be proven.

15. Until more applications are proven feasible, there is some doubt that robots can improve productivity, (a counter comment indicates that significant productivity improvement comes with the *use* of robots & positioners - e.g. more arc time if used for welding).

16. Adopting robotics will generate growing pains, but they can be minimized by starting with existing technology before proceeding to develop new technology.

17. Once the decision is made to consider the use of robots, the following factors are minimal requirements:

a. first applications must have <u>now</u> solutions;

b. the robot is not as versatile as the human, therefore the approach must be changed to adapt to the robot;

c. the robot must have tooling and peripherals;

d. peripherals must be arranged so that the robot has a defined environment in which to work; and

e. the robot must be fed, therefore material handling systems will have to be revised.

SECTION III

WORKSHOP PANEL REPORTS

3.1 Panel I - Welding and Assembly

Chairman:

John Maciel, Manager, Welding Engineering
Todd Pacific Shipyards Corporation, Los Angeles Division

3.1.1 Panel I Discussion Items

The panel covered a wide range of potential applications and problems associated with the introduction of robotics into welding and assembly tasks. The discussion led to a general consensus that shipbuilders must do a self-examination/evaluation to determine its present condition/status (vis-a-vis robotics technology) in modern day shipbuilding technology. The questions to be addressed and the actions required to determine their solution are summarized herein.

3.1.1.1 What are our current capabilities in relation to available present day (vis-a-vis) shipbuilding technology? In order to determine these we must:

1. Evaluate the present production system;
2. Evaluate the effective utilization of the work force;
3. Define problem areas; and
4. Define present and future goals.

3.1.1.2 What can be done to upgrade shipyard facilities in order to integrate robots (or similar automatic machines) into the production process? Determining this will require:

1. Developing a plan; and
2. Implementing that plan.

3.1.1.3 How will shipbuilders accomplish the introduction of robotics (and similar technologies) into present day shipbuilding environments? Although schedules will vary by shipyard, as an industry the following actions will be necessary:

1. Establish project teams;
2. Develop a strategy to interface and/or coordinate efforts of the shipbuilders, the governmental agencies, equipment manufacturers and educational institutions;
3. Increase Research & Development efforts in the shipbuilding industry;
4. Devise a strategy to utilize government funded programs;
5. Seek out lease and lease/option robotics manufacturing services;
6. Utilize existing educational institutions and manufacturer facilities for new and displaced technology; and
7. Utilize independent source to evaluate and qualify robotic systems.

3.1.1.4 When should the shipyards commence action on these items?

1. They should have already commenced establishing direction for improving the present production system by utilizing existing technology; and
2. They should commence moving into advanced technology NOM.

3.1.2 Summary of potential areas of research into the application of robotics.

1. Straightening operations
2. Moveable vs. stationary robots
3. Gantry mounted robots
4. Software improvements for robotics
5. Determine robot limitations
6. Develop new sensor systems
7. Develop tracking systems
8. CAD/CAM interface
9. Teaching system evaluation/improvements

10. Develop feed back systems.

   a. Meld joint geometry variation compensation

   b. Fit up variation compensation

   c. Compensation for variance from established point location of production part.

11. Integrate existing surface measuring system technology with welding robot (e.g. Navy propeller measuring system).

12. Interface inspection processes with welding robot.

   a. Ultrasonic

   b. Radiographic

   c. Weld size

   d. Surface irregularity/flow measurement

13. Simplify multiple pass welding programs.

14. Develop programming peculiarities & supply programming for multiple pass welding.

15. Laser welding by robots.

3.2 Panel II - Surface Preparation - Coating & Material Handling

Chairman:

W. S. Whipple, Project Manager Facilities Development
Todd Pacific Shipyards Corporation, Los Angeles Division

3.2.1 Panel II Discussion Items

The panel immediately set about identifying the reasons for adapting robotics to the surface preparation/coating and material handling tasks as applicable to the shipbuilding and repair industry. It was determined that the application of robotics to surface preparation/coating tasks can probably remove the human operation from the potential hazards associated with them.

3.2.1.1 Surface preparation is at best a task with high potential safety and health hazards. Controlling these hazards to make an acceptable environment for human operations significantly increases costs and reduces equipment efficiency. A robot operator can perform much of this task with much less environmental control in the operating area.

3.2.1.2 Surface coating is a task with high potential health hazards. As with surface preparation a robot can perform much of this task with only minimal environmental protection.

3.2.1.3 Surface preparation and coating are labor intensive tasks where human operators using heavy and awkward equipment are significantly affected by fatigue. Robot operators are not subject to reduced efficiency because of fatigue.

3.2.1.4 In a brief discussion of the material handling no one on this panel could identify a specific machine loading/unloading application since none of the shipyards present had sufficiently large batch runs of manufactured items to make this application attractive.

3.2.1.5 The remaining discussion time was spent on the subject of controlling material which is removed from a repair or conversion project, reconditioned, stored and then reinstalled on the ship. It was generally agreed that an automated warehouse storage and retrieval system could make a significant contribution to savings and that robotics could be used in this area.

3.2.2 The group next addressed the areas where robotics can or should be applied. The summary of potential areas of research are listed in order of importance.

1. Exterior hull divided into side and bottom segments. The group agreed that these areas were the most cost effective because of the surface area concerned and state of existing technology.
2. Interior hull divided into tanks and other areas. This area of study requires more technological development but because of the large surface area involved and the potential hazards to personnel it still is a very promising area of cost improvement.
3. Preweld, weld joint preparation is an area of intense manual labor. This area has received very little attention. The group, especially the production management type, are very interested in having this process studied for robotics application.
4. Special prepaint cleaning, most specifically chemical cleaning, is another area where the production management types are anxious to find a method of getting robots into this basically hostile environment.
5. Raw material surface preparation and coating was placed low in the order of priorities because this process has received most of the attention in the past and is already highly mechanized. This area is still worthy of additional study.

3.3 Panel III - Industrial/Manufacturing Engineering, IREAPS and other Applications

Chairman:

R. Bradley, Manager of Industrial Engineering
Newport News Shipbuilding Company

3.3.1 Panel III Discussion Items

Since this panel was not charged with examining specific areas for potential application of robotics, the discussions were approached from the point of view of the Industrial and Manufacturing Engineer. They were directed toward efforts to reduce flow time and man hours, improve quality, and minimize the problems inherent in facilitating a new technology. As a result, there were some overlap of items considered by panel I and II, with some differing conclusions. In addition, the potential problems associated with using such sensitive machines in the shipyard environment were brought into focus.

3.3.2 Summary of potential areas of research into the application and use of robotics.

1. Create a generic specification for a high level compiler for application programing (for example CAD/CAM interface). The purpose is to enhance technology exchange between industry and the robotic manufacturer.
2. Real time UT/MT inspection using an external sensor.
3. Materials handling
    a. between work centers
    b. loading/unloading a machine center
    c. stacking to a palet
    d. control moves for overhaul and ship repair material
    e. load/unload x-ray cell or vat
    f. bin picking for tool issue and small parts issue.

4. Structural shape cutting.
5. Sheet metal and non-structural bulk head positioning and spot welding.
6. Inspection and dimensional checking of structural shapes.
7. Multi blast and paint work stations with vision remote controlled with a minimum level of supervision.
8. Apply vision to sort, route and mark 2 D cut metal shapes.
9. Feasibility study on the external environment and robotic applications.

SECTION IV

CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

The collective efforts of participants in the Workshop through discussions in the general sessions and panels developed a number of significant conclusions.

1. While the application of robotics technology to the shipbuilding industry cannot be a panacea, it can be an excellent tool for improving productivity if we pick the applicants carefully and utilize them properly.
2. In order to apply robotics technology, a program is needed and must be developed by the shipbuilding industry, working with Robotics manufacturers and educational institutions and supported by MARAD and the Navy.
3. In order to best meet the requirements of all participants in a robotics program, we need to develop a "road map" that will tell us how to:
   a. Best transfer the technology now existing,
   b. Develop and apply new technology, and
   c. Target applications to the high cost drivers in the industry.
4. Time is of essence in order to allow sufficient lead time for budgeting of support funding by MARAD and the Navy.

4.2 Recommendations

Review of the roundtable sessions, panel recommendations and the overall conclusions by the participants result in the following recommendations:

1. Increased promotion of robotics technology and its application to the shipbuilding industry.

2. Develop a program in which the shipbuilding industry takes the lead and works with robotics manufacturers and educational institutions to apply robotics technology to the industry.

3. Establish a Shipbuilding Robotics panel under the Ship Production Committee of the Society of Naval Architects and Marine Engineers (SNAME) to take action on these recommendations and continue the work of this workshop including responsibilities to act for the industry in coordinating a cooperative technical program with the Maritime Adminstration and the Navy and:

   a. Develop a "road map" for transferring existing and developing/ applying new robotics technology;

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   c. Solicit and review proposed robotics research projects which address problem areas;

   d. Coordinate the efforts of other SNAME panels proposing robotics applications;

   e. Maintain an up-to-date awareness of robotics technology as it applies to shipbuilding technology;

   f. Provide continuing program guidance and overview;

   g. Publish and disseminate research results to the industry;

   h. Maintain a flexible program with redirection capability to address new problems/technology as they arise; and

   i. Schedule periodic technical meetings for the shipbuilding industry.

APPENDIX A

WORKSHOP REGISTRATION LIST

REGISTRATION

ATTENDANCE LIST

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LONG BEACH, CALIFORNIA
OCTOBER 13-16, 1981

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APPENDIX B

WORKSHOP AGENDA

AGENDA

ROBOTICS IN SHIPBUILDING WORKSHOP
OCTOBER 13 - 16, 1981
R.M.S. QUEEN MARY
LONG BEACH, CALIFORNIA

OCTOBER 13, 1981 (TUESDAY)	TIME	LOCATION
Registration	4:00 - 8:00 P.M.	ABBY ROOM
Reception	6:00 - 8:00 P.M.	KING'S GRILLE

OCTOBER 14, 1981 (WEDNESDAY)		
Registration	7:30 - 8:00 A.M.	ABBY ROOM
Opening Remarks L. Thorell, General Chairman, General Manager, Todd Pacific Shipyard, Los Angeles	8:00 - 8:15 A.M.	REGENCY ROOM
Marad Robotics Program J. Garvey Director, Advanced Ship Development Maritime Administration	8:15 - 8:45 A.M.	REGENCY ROOM
U.S. Navy Robotics Program W. Holden General Engineer U.S. Naval Material Command	8:45 - 9:15 A.M.	REGENCY ROOM
Film: Robotics in Japanese Industry Courtesy Automatix, Inc.	9:15 - 9:45 A.M.	REGENCY ROOM
Break	9:45 -10:00 A.M.	
Robotics Mechanisms Professor Del Tessar Director, Center of Intelligent Machines & Robots (CIMAR) University of Florida	10:00 -10:40 A.M.	REGENCY ROOM
Robotic Sensors & Systems (Aerospace) Edmund R. Bangs IREAPS Program Manager IITRI	10:40 -11:20 A.M.	REGENCY ROOM
Integration of Components Into A Robotic System Phillepe Villers President Automatix, Inc.	11:20 -12:00 A.M.	REGENCY ROOM

AGENDA

ROBOTICS IN SHIPBUILDING WORKSHOP
OCTOBER 13 - 16, 1981
R.M.S. QUEEN MARY
LONG BEACH, CALIFORNIA

	TIME	LOCATION
.unch	12:00 -1:30 P.M.	KING'S GRILLE
:ommerical Shipyard Requirements (Roundtable) An Overview of Shipyard Requirements for Improving Productivity & Reducing the Number of People doing Undesirable Tasks as Seen by Attending Shipyard Executives James W. Tweeddale, Chairman	1:30 -3:30 P.M.	REGENCY ROOM
3reak	3:30 -3:45 P.M.	
Jorkshop Session # 1 - Brainstorming Sessions for Potential Areas of Research	3:45 -5:00 P.M.	
Group # 1 - Welding Assembly		REGENCY ROOM
Group # 2 Surface Preparation & Coating Material Handling		OXFORD ROOM
Group # 3 Facilities, Industrial & MGF. ENGR. IREAPS Other Applications		ASCOT ROOM

)CTOBER 15, 1981 (THURSDAY)

\dministrative Remarks J. B. Acton, Administrative Chairman	8:00 -8:15 A.M.	QUEEN'S SALON
Human Implications for Robotic Systems Peter L. Blake Executive Director Robotics International of SMA	8:15 -8:45 A.M.	QUEEN'S SALON
:conomic and Transitional Issues of Robotic Systems Steve Miller Lecturer, Robotics Institute Carnege-Mellon University	8:45 -9:35 A.M.	QUEEN'S SALON
-e of Robotics in Shipbuilding Jan H. Kremers Computer Scientist, Industrial Automation Artificial Intelligence Center, SRI International	9:35-10:15 A.M.	QUEEN'S SALON

AGENDA

ROBOTICS IN SHIPBUILDING WORKSHOP
OCTOBER 13 - 16, 1981
R.M.S. QUEEN MARY
LONG BEACH, CALIFORNIA

	TIME	LOCATION
̣reak	10:15 -10:30 A.M.	
)perational Factors in Robotic Systems Joe Ray Chief Engineer Robotics Division Cincinnati - Milacron	10:30 -11:15 A.M.	QUEEN'S SALON
\vailability of Robotic Systems Components Mortimer J. Sullivan Manager of Sales Unimation	11:15 -12:00 A.M.	QUEEN'S SALON
.unch	12:00 - 1:30 P.M.	REGENCY ROOM
)pen Discussion Between Shipyards 1ajor Shipyard Suppliers & Suppliers)f Robotic Systems E. J. Petersen, Chairman	1:30 - 3:30 P.M.	QUEEN'S SALON
3reak	3:30 - 3:45 P.M.	
4orkshop Session # 2 Groups Complete Brainstorming & Prepare Reports	3:45 - 5:00 P.M.	QUEEN'S SALON OXFORD ROOM ASCOT ROOM
Reception	6:00 - 7:00 P.M.	RED LION ROOM
Dinner	7:00 - 8:30 P.M.	FLAMENCO ROOM

OCTOBER 16, 1981 (FRIDAY)

Workshop Chairman Report to Plenary	8:00 - 8:45 A.M.	KING'S GRILLE
Speaker's Commentary (Limit 6 Minutes ea.)	8:45 - 9:45 A.M.	KING'S GRILLE
General Chairman's Summary	9:45 -10:00 A.M.	KING'S GRILLE
Break	10:00 -10:15 A.M.	
Proceed to Todd Shipyard	10:15 -11:00 A.M.	
Demonstration of Cincinnati-Milacron T-3 Robot Welder Center	11:00 -12:00 A.M.	TPLA PLATE SHOP
̣ljourn	12:00 NOON	

APPENDIX C

REPRINTS OF SELECTED SPEAKER PRESENTATIONS

"Some Applications and Limitations of Industrial Robots in Shipbuilding"

(Slides)

Willaim F. Holden
General Engineer
Navy Material Command Headquarters
Washington, D.C. 20360

"Personnel Implications For Robotic Systems"

(Slides)

Peter L. Blake
Executive Director
Robotics International of SME

"Robotics in Shipbuilding"

Jan H. Kremers
SRI International
Menlo Park, California 94025

"Availability of Robot Systems Components"

Mortimer J. Sullivan
Manager of Sales
Unimation, Inc.
Danbury, Conneticut 06810

"Closing Remarks"

Dr. James W. Tweeddale
Director, Productivity Management
Office of the Asst. Secretary of the Navy (MRA&L)
Washington, D.C. 20360

Some Applications & Limitations of Industrial Robots in Shipbuilding

by

William F. Holden

C-A-1

LIMITATIONS IN THE UTILIZATION OF ROBOTICS IN SHIPBUILDING

Shipbuilding Characteristic	Robot System Limitation
■ Fixed Point Construction	■ Mobility
■ Lot Size	■ Programming Time
■ Size	■ Reach
■ Weight	■ Load Capability
■ Accuracy	■ Adaptability

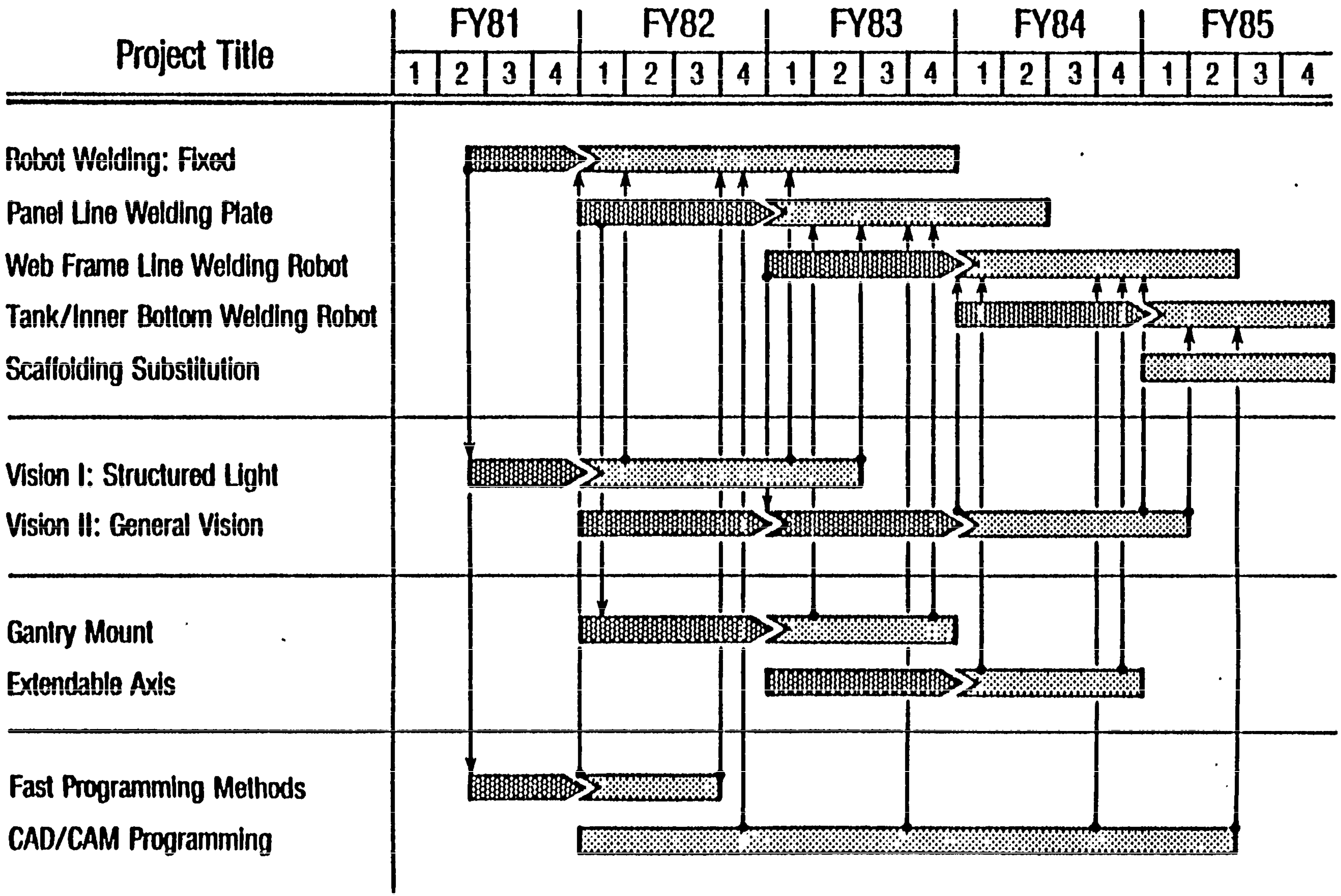
SHIPBUILDING PRIORITIES FOR ROBOTICS TECHNOLOGY DEVELOPMENT

1. Off-line programming from CAD/CAM data base - LEARNING
2. Mobility with accurate position feedback
3. Vision systems capable of operating in low contrast environment

PRODUCTIVITY FACTORS IN AUTOMATED WELDING

Factor	Stick Electrode (Manual)	Automatic Pipe Welding (600 amp)	Robot Welder (600 amp)
Max. Deposition Rate (lb/hour)	2.10	4.00	4.00
Operator Factor (%)	25.00	60.00	80.00
Productivity Factor (%)	85.00	98.00	98.00
True Deposition Rate (lb/hour)	.45	2.35	3.14

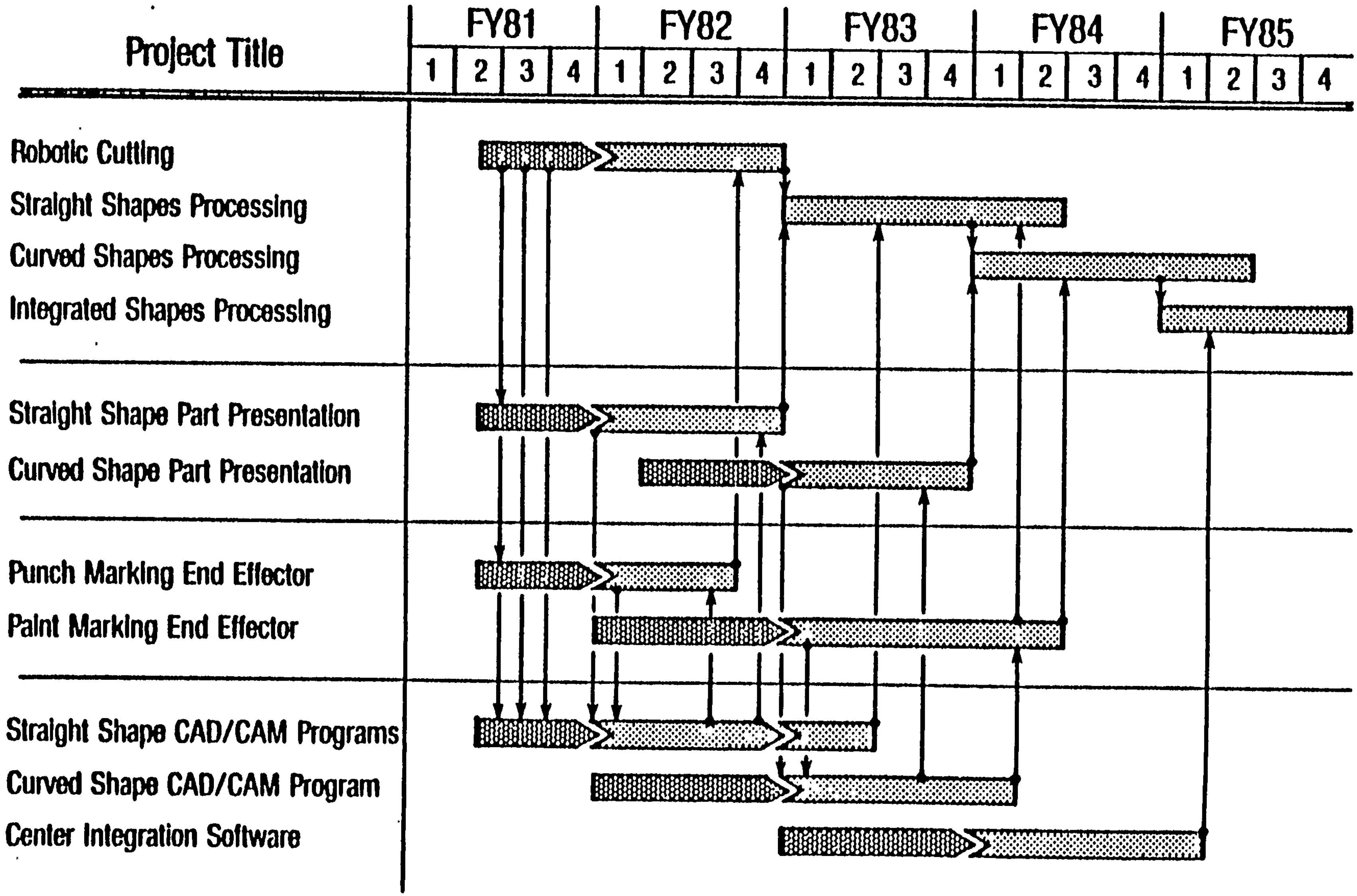
ROBOTIC WELDING ROADMAP



COST/BENEFIT SUMMARY FOR ROBOT CUTTING SYSTEMS

Cost/Benefit	Fixed Base	4-Robot Profile	Portable
Initial Costs ($)			
— Robots	100,000	120,000	30,000
— Support	6,000	104,000	5,000
— Other	20,000	40,000	0
Changes (annual)			
— Labor (man year)	15	39	1.6
— Other	−5,000	−10,000	−500
Output Value (annual) (man years)	2.4	6	.25
ROI (%)	206	251	30

ROBOTIC CUTTING ROADMAP



PRODUCTIVITY FACTORS IN GRINDING

Category	Manual	Robot
Operator Factor	25-50%	80-90%
Tool Weight	10-15 lbs.	50-100 lbs.
Material Removal Rate	Ref.	10 Times Ref.

PRODUCTIVITY FACTORS WITH ROBOT BLASTING

Factor	Expected Effect
Technology	Considerable more power may be applied and larger shot used. Shot may be recycled.
Quality	More complete cleaning because of increased power and shot size.
Throughput Material	Rates 5 to 10 times human capabilities may be possible.

PRODUCTIVITY FACTORS WITH ROBOT PAINT SPRAYING

Factor	Expected Effect
Technology	More viscous or more toxic materials may be used. Minor change expected.
Quality	More uniform and controlled coverage is expected.
Throughput	Similar to human capability for single head. Multiple spray heads might be employed.

COST/BENEFIT SUMMARY OF CONCEPTUAL DESIGNS

Concept	Initial Cost ($)	Equivalent Production (Man yr/yr)	Estimated ROI (%)
Fixed Welding Robot	123,000	3.22	34
Advanced Fixed Welding Robot	200,000	5.85	38
Advanced Portable Welding Tractor	79,000	.67	5
Advanced Portable Orbital Welder	35,000	.67	34
Fixed Base Cutting Robot	126,000	17.40	206
Advanced Fixed 4-Robot Cutter	264,000	45.00	251
Portable Cutting Robot	35,000	1.85	30
Fixed Grinding Robot	130,000	15.00	190
Advanced Fixed Painting	103,000	1.12	2
Fixed Remote Blast Cell	223,000	10.50	78

RATING SCALE FOR ROBOT WELDING SYSTEM, MANUALLY PROGRAMMED

Category	Maximum (Points)	Score (Points)
Economics	100	60
Initial Cost	50	30
ROI	30	10
Risk	20	20
1. State-of-Art	5	5
2. Experience	5	5
3. Success	5	5
4. Pressure	5	5

RATING SCALE FOR ROBOT WELDING SYSTEM, MANUALLY PROGRAMMED

Category	Maximum (Points)			Score (Points)		
Technical	100			67		
Availability		60			43	
1. Robot			10			10
2. Sensor			10			10
3. Software			10			0
4. Tool Pack			10			10
5. Controls			5			0
6. Computer			5			5
7. Fixtures			5			5
8. Transport			5			3
Flexibility		20			14	
1. Appl. Range			8			2
2. Appl. No.			6			6
3. General			6			6
Adaptability		10			10	

RATING SCALE FOR ROBOT WELDING SYSTEM, MANUALLY PROGRAMMED

Category	Maximum (Points)		Score (Points)
Social Desirability	100		70
OSHA	60		60
12. Heavy (B)		No	
2. Noxious (A)		Yes	
3. Dusty (B)		No	
4. Ext. Temp. (B)		Yes	
5. Dangerous (A)		No	
6. Hot Parts (A)		Yes	
7. Noise (B)		No	
8. Toxic (A)		No	
9. Dirty (B)		Yes	
Task Related	30		10
1. Factor 1		Partial	
2. Factor 2		No	
Displacement	10		0

ROBOT EVALUATION MATRIX RESULTS
(Assuming R&D Problems Will be Solved)

Robot Concept	Economic (50%)	Technical (30%)	Social (20%)	Weighted Score	Rank
Fixed Welding	62	84	70	70	B
Advanced, Fixed Welding (Dual arm)	68	84	70	73	A
Advanced Welding Tractor	66	90	70	74	A
Advanced Orbital Welder	72	90	70	76	A
Fixed Cutting	64	84	80	73	A
Advanced Four-Robot Cutting	54	79	70	65	C
Portable Cutting	58	90	70	70	B
Fixed Grinding	60	79	60	66	C
Advanced Fixed Painting	36	80	80	58	D
Fixed Remote Blasting	50	86	80	67	C

ROBOT EVALUATION MATRIX RESULTS
(State-of-the-Art-Designs)

Robot Concept	Economic (50%)	Technical (30%)	Social (20%)	Weighted Score	Rank
Fixed Welding	62	67	70	65	A
Fixed Cutting	64	56	80	65	A
Portable Cutting	58	86	70	69	A
Fixed Grinding	54	54	60	55	C
Remote Blasting	42	76	80	60	B

"PERSONNEL IMPLICATIONS FOR ROBOTIC SYSTEMS"

Peter L. Blake
Executive Director
Robotics International of SME

Robots should only be installed when it is in the best interest of all concerned parties (management and workers).

1. Economics
2. Practicality
3. Environment

The installation of robots should involve the supervisors, operators and maintenance people that will be responsible for the installed robot(s).

A. Get involved early
B. Keep Involved
C. Encourage their ideas/suggestions
D. Form a partnership

The development of plans to install robots should not be done secretly.

A. Shop Management
B. Production People
C. Unions
D. Maintenance
E. Media/Public

C-R-4

"I didn't want to get it—but my management made me"

Education and training should be considered part of the expense of a robot installion,

A. An investment

B. Two Phases

   a. Programming and Operator Training

   b. Preventive Maintenance & Trouble Shooting

C. Who should be trained

D. Where should they be trained

E. When should they be trained

Make safety a must in your robot operation

A. Workforce Safety
B. Robot Safety
C. Other Machines Safety

The future

A. Labor Displacement

B. Handling of Displaced Workers

C. Training requirements of transferred workers

Robotics
Labor Displacement
Potential vs. Actual
1980 Forecast (Cumulative)

	1980 Employment (Millions)	Potential Displaced 1990	Actual % Displaced 1990
Assemblers	1.300	10%	5%
Checkers	.750	10%	6%
Packers	.630	10%	4%
Painters	.190	20%	15%
Welders/ Flamecutters	.710	15%	10%
Machinists	3.020	10%	6%
	6.600		

Robotics
Labor Displacement
1990 Forecast (Cumulative)

	% Displaced By 1990	1980 Employment (Millions)	Displaced By 1990 (Thousands)
Assemblers	5	1.300	65
Checkers	6	.750	75
Packers	4	.630	25
Painters	15	.190	28
Welders & Flamecutters	10	.710	71
Machinists	6	3.020	180
		6.600	444

Robotics
Handling of Displaced Workers
1990 Forecast (Cumulative)

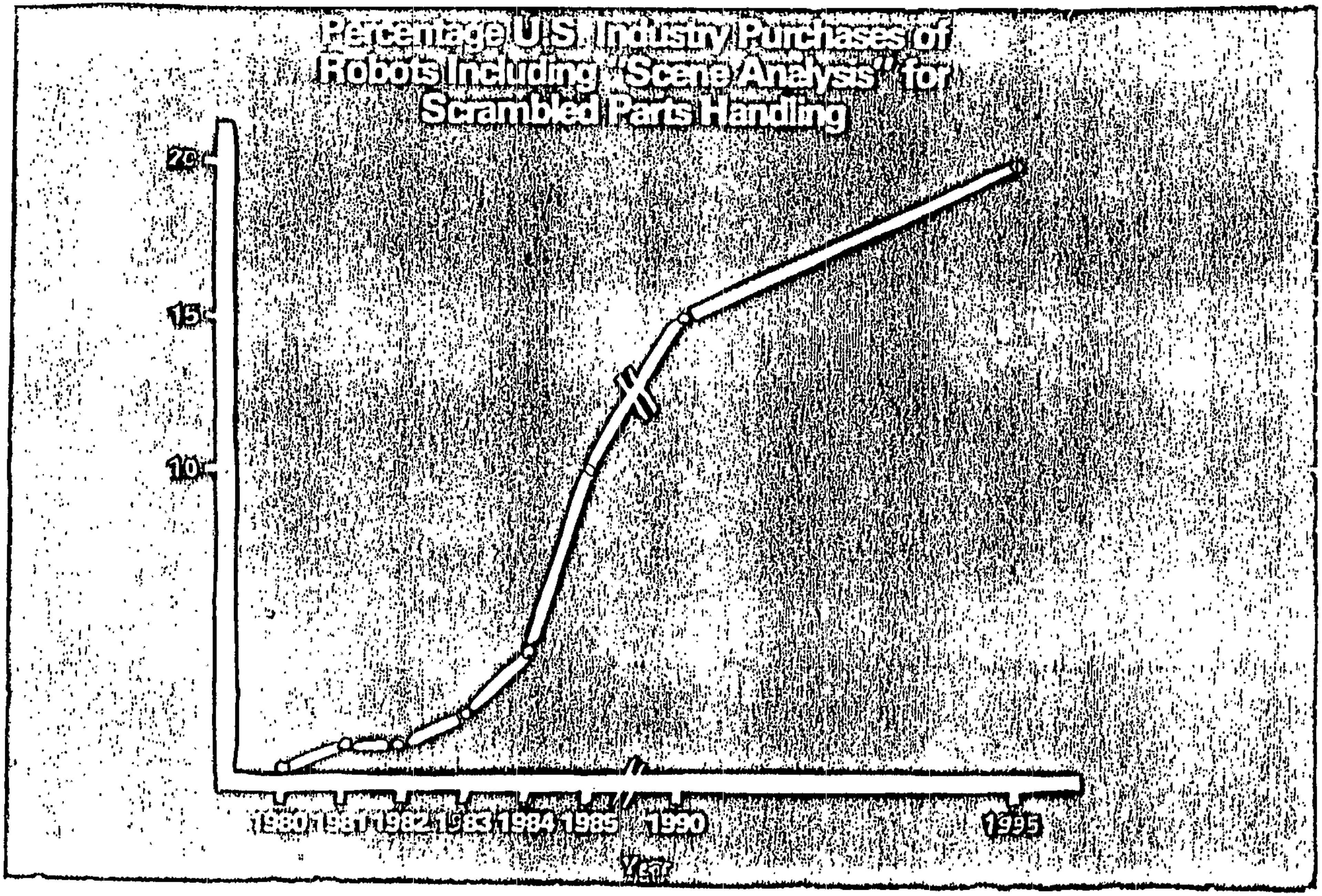
Workers Displaced—1990	444,000
Transferred—90%	400,000
Early Retirement—5%	22,000
Terminated—5%	22,000*

*Some may be required for maintenance and programming.

Robotics
Training Requirements Of Transferred Workers

	1980-85	1985-90
Without Training	55%	40%
Retrained— Same Plant	35%	50%
Retrain— Sister Plant	10%	10%
TOTAL TRANSFERRED	100%	100%

"The robots are coming—
The robots are coming"


Percentage U.S. Industry Purchases of
Robots Including "Scene Analysis" for
Scrambled Parts Handling
20
15
10
1980
1981
1982
1983
1984
1985
1990
1995
Year

"A robot may take a human's job—but never make a human jobless"

Skole's Law

ROBOTICS IN SHIPBUILDING

By Jan H. Kremers

SRI International, Menlo Park, California

Presented at

Robotics in Shipbuilding Workshop

13-16 October, 1981

R.M.S. Queen Mary

Long Beach, California

Slide Nl: Robotics in Shipbuilding: Introduction

* Application of robotics to shipbuilding has three major advantages:

  - Increasing the productivity of shipbuilding through advanced automation.

  - Meeting OSHA and EPA regulations by displacing human workers from jobs that are harmful, dangerous, and strenuous.

  - Preparing the nation for emergency in which Navy ships must be rapidly constructed.

* Despite these advantages, and despite the fact that industrial robots have been employed by other sectors of industry--no robots are being used currently by U.S. shipyards. I can think of three major reasons for this problem:

  - Automation in U.S. shipbuilding lags behind that in Japan and Europe, and other U.S. industries

  - Only few ships of a given type are built totally. Consequently, the cost of setup and robot training for one-of-a-kind jobs is high compared with a high volume batch production.

  - Today’s robot cannot perform many jobs in shipbuilding because they are not adaptable, manueverable, or sufficiently mobile.

> Adaptability is needed to sense variations in workpiece dimensions, location, or fitup.

> Manueverability is needed *to* reach workplaces around obstacles, such as pipes and stiffeners.

> Mobility is needed for operation on workplaces that are too large for conventional fixed robotics.

* These problems may be solved by the following methods:

  The automation lag in U.S. shipbuilding can be alleviated by government help to advance automation and by economic incentives for shipyards to invest in advanced automation.

  The “few of a kind” problems can be mitigated by development of methods for efficient programming of robots for new jobs.

  Robotic adaptability can be achieved by equipping the robots with sensors and computer control; robotic manueverability may be achieved by multi-joint arms; and robotic mobility can be achieved by using portable robotic devices and semiautonomous teleoperators.

Slide N2: SRI <u>Study</u> on <u>Advanced Automation for Shipbuilding</u>

* The Navy’s Manufacturing Technology Program under the management of the Naval Material Command has supported a small project at SRI to study the application.of robotics to shipbuilding.

* The project objectives were to

  (1) Study existing shipbuilding tasks.

  (2) Determine and prioritize the tasks that can be implemented by robots.

  (3) Conceptually design robotic systems for these tasks, and identify R&D issues that require further investigation.

* Our method of approach included

  (1) Literature survey and visits to four shipyards (National Steel and shipbuilding, San Diego, CA; Newport News Shipbuilding, Newport News, VA; Ingals Shipbuilding, Pascagoula, Miss; Avondale Shipyards, New Orleans, LA).

  (2) Task prioritization based on technoeconomic analysis and consideration of working environment.

(3) The conceptual designs were based on application of commercial and laboratory robotic technology. In the process of design, R&D issues were identified by extending current R&D efforts.

This work was documented in a final report, which is now available from the project sponsor.

Slide N3: Organization of Robot System in Shipbuilding

This slide summarizes the results of our study.

We identified shipbuilding tasks that should be performed by industrial robots based on technoeconomic and working-life incentives. These tasks are arc welding, flame and plasma cutting, grit and sand blasting, spray painting, and grinding.

The robot systems for performing these jobs consist of industrial robots with associated tools, sensors and control computers.

The robot system may be trained to execute the various processes associated with these shipbuilding tasks in a programming station. Programming is done by an operator either manually, using a control box, or interactively, using a programming computer that is connected to a CAD/CAM data base.

Slide N4: Robot Programming Methods

Three robot programming methods are distinguished.

(1) Manually programming the robot itself.
(2) Manually programming an auxiliary measurement arm.
(3) Interactively programming the robot off-line, using CAD/CAM data base.

Two schemes for manually programming the robot are distinguished:

* Remotely using a control unit, such as

  - A button gun, moving the robot in joint coordinates.
  - A button box, moving the robot in Cartesian coordinates.
  - A scaled down replica of the robot.

* Leading the robot by its hand. This scheme is applicable to robots that are not too large, e.g., human size.

Slide N5: Manual Programming Using a Robot

This is a cartoon showing manual programming of the robot itself. The trainer uses a control box remotely to lead the robot along the workpiece. The same robot then performs the actual work.

The drawback of this method is that the working robot is interrupted frequently for programming one-of-a-kind tasks.

Slide N6: Programming with Aid of a Measurement Arm

The above drawback is eliminated by using a measurement arm in a programming station that is separated from the robot workstation. Efficient operation requires that programming will be done faster than the task execution. To be on the safe side, a measured part should be waiting for the robot to complete its job.

The manual programming methods shown in this slide and the previous one could be further augmented by using CAD/CAM data base and a sensory system, guided by that data base, that locates and measures the actual workpiece. Furthermore, such off-line programming method can be extended to automatic calibration of the workpiece in the robot workstation by locating a few landmarks.

Slide N7: Five-Axis Measuring System

This slide shows a 5-axis arm developed by Eaton-Leonard for measuring three-dimensional pipes. It is moved manually to critical positions. Alternatively, it could be moved and stopped automatically by using a tactile sensor if the part were jigged, or by using tactile and visual sensors otherwise.

Slide N8: Robot Programming R&D Issues

The R&D issues in robot programming are as follows:

* Use of sensors to locate and inspect workplaces. A mixture of noncontact and contact sensing should be explored. The noncontact sensing could include binary, gray scale, or color vision, and range data.

* To be efficient robot programming should be done *as* automatically as possible. For this purpose we must first model the workpieces, robotic systems, and the various processes in shipbuilding.
* We must then develop computer expert systems for shipbuilding on the basis of that model. Specifically, we will use the model for:

  - Interactive design of workplaces *to* (1) match the advantages and limitations of programmable robotics and (2) plan the sequence of assembly to minimize storage and material handling cost .

  - Interactive planning of material handling, inspection, and assembly processes, using Artificial Intelligence Techniques.

  - To bridge between the model and the planner, work is needed to represent the shipbuilding in the computer.

  - The output of the planner will be used to generate execution programs for shipyard robots.

Slide 179: Modeling Computer-Aided Design and Planning of Programming Assembly

This slide shows a block diagram of the research issues that I have just described. A dashed-line box represents research staff; a solid-line box represents a computer program.

Research staff will analyze shipbuilding workpieces, workstations, and processes based on existing and new technologies, and generate a model for robotic shipbuilding. That model will be used interactively as part of CAD to design workplaces that match robotic technology and to plan the assembly sequence. An interactive planner of assembly operations will be developed on the basis of the assembly sequence and a computer representation of the model for robotic shipbuilding. Finally, a code generator will be developed to convert the output of the planner into execution programs for the shipyard.

Slide N1O: Robotic Arc-Welding Incentives

I now wish to turn to the robotic shipbuilding tasks described in our report, including incentives, existing technology, conceptual design for robotic workstations, and R&D issues.

* Arc welding is the most labor intensive job in shipbuilding, approximately 15% of the total. manual work. About 2/3 of the welders weld structures, which is partially automated using mobile welding carts and other semiautomatic devices. About 1/3 of the welders weld pipes, which is fairly mechanized.
* The incentives for robotic *arc* welding are only for structures because pipe welding is fairly automated. Compared with manual arc welding, robotic welding may be up to 6 times more productive due *to* increased arc-time.

Slide NIL: Existing Arc-Welding Automation

Existing arc-welding devices that are automated or semiautomated include industrial robots, portable welders, and pipe welders.

* Industrial robots are applied to arc welding primarily in Japan, less than Japan in Europe, and less than Europe in the USA. This application requires workpiece indexing because robotic sensing is either rudimentary or nonexistent.
* Two types of portable structure welders are distinguished:

  Mobile carts, which are started and monitored by human operators.

  Others such as Unimation's apprentice arm.

Slide N12: Unimate 2000 Robot Welding Housing

This slide shows a Unimate 2000 robot welding and indexed structure.

Slide N13: Unimation's Apprentice Arm Shipwelding.

Unimation developed a 200-pound portable arm for welding structures in cramped spaces, such as aboard ship. A programmer lads the end-effectors along the seam, and then the Apprentice welds that seam.

Slide N14: Semiautomatic Pipe Welding Head on Round Track

Several suppliers make semiautomatic pipe welding equipment. The weld head follows a track to weld the pipe.

Slide N15: Robotic Arc-Welding R&D Issues

Robotic arc welding entails the following R&D issues:

* Existing industrial robots are flexible but not adaptable. Adaptive control of welding is necessary for:

  - Sensing the joint position and gap variations in three dimensions ahead of the arc. This is especially important for heavy workpieces, where indexing is impractical.

  - Sensing the puddle shape and the temperature distribution around it to achieve proper weld penetration.

  - Using the above sensory data to serve the torch and welding parameter.

* Inspection of the weld quality is also an R&D issue. Here we distinguish between

  - Surface inspection, which can be done with visual sensing.

  - Interior inspection, which can be done with acoustic or x-ray sensing.

* The last R&D issues are portability, mobility, and accessibility of welding robots to be used

  - In cramped assemblies
  - Aboard ship.

  For example, portability may be solved by building lighter robots (e.g., using fiber graphite), mobility by using tracks or legs, and accessibility by building a snake-like robot with many joints and short links.

Slide N16: Sensors for Robotic Arc Welding

Several sensors have been applied by industry to guide automatic arc welders:

* Contact sensors are used to measure the joint position by means of

  - Wheels that are attached to the welding carts
  - Electromechanical probes.

* Eddy current sensors are used to sense the position of a torch performing fillet-joint welding relative to the *two* plates.
* Arc resistance sensors are used to sense the joint position.
* Visual sensors can be used to sense the joint position and gap, the puadle shape and size, and to inspect the surface. Evidently, visual sensors can provide almost all the information required for automated arc welding.
* Acoustic sensors can be used *to* inspect the weld interior.

Slide N17: Projects on Automatic Welding with Vision

The importance of using vision in automated arc welding has been recognized by several researchers in the industrialized world. For example:

* NASA's Marshall Space Flight Center has developed an automated system for welding aluminum sheet metal. They use
  - Incandescent light projected on beveled butt joint.
  - The reflected *image* is used to seno the torch.
* Kawasaki Heavy Industries in Japan uses
  - A planar laser light that is projected across the joint.
  - The image of the intersection line was used to servo a Unimate robot.
* Mitusi Shipbuilding in Japan used
  - A xenon light that is projected on a fillet joint at 65 degrees to the horizontal.
  - The image intensity change is sensed and used to servo the torch.
* Finally, we at SRI have been working on use of machine vision to servo the arc-welding torch. Let me describe this work briefly.

Slide N18: Block Diagram of Visually Guided Robot Arc Welding system

SRI has developed a visually guided robotic arc welding system that uses structured illumination *to* determine the 3-dimensional location, geometry, and fitup of a weld joint. This system operates in real-time (in the presence of the welding arc), and is capable of making fillet, lap, or butt welds using the MIG welding process. This slide shows a block diagram of this system. The major system components are:

* A Cincinnati-Milacron T3 robot
* A Hobart Semi-automatic Arc Welding System, interfaced to the T3 controller
* A Structured Light Projector
* A General Electric model Tn2500 solid-state TV camera with SRI-designed interface
* Special hardware to facilitate image acquisition in the presense of the welding arc.
* DEC PDP-11/34 and LSI/11 computer systems.

slide N19: Robotic Arc Welding System in operation

This is a photograph of the visually guided robot welding system in operation. The system operates by projecting a structured light pattern onto the workpiece a short distance ahead of the welding arc. The resulting distorted pattern is viewed by the camera. The camera image is analyzed by the computer and the resulting data used to guide the robot along the joint, and to adjust the welding procedure to accommodate variations in fit-up, etc..

Slide N21: Close-up of Structured Light Pattern on Workpieces

The planes of light intersect the workplaces along chevron-shape lines.

Slide N22: TV Image of Illuminated Workpieces

This is the TV image of the illuminated workplaces. The image is analyzed by the computer. The analysis includes noise rejection and fitting of straight lines, planes, and their intersection in three dimensions.

Slide N23: Processed Image Showing Joint Line

This is the image of the lines processed by the computer: the lines fitted to the data, and the line of intersection between the two planes formed by the bottom and top group of fitted lines.

Slide N24: Completed Fillet Weld

As the robot moves along the joint, a pictures are taken approximately 3.5 inches apart. The location of the joint line is determined and the data for each segment of the joint stored for use by the *robot* control when the welding gun arrives at the imaged point. This slide shows a example of a short fillet weld performed by the robot.

ROBOTICS IN SHIPBUILDING: INTRODUCTION

* ADVANTAGES
  - INCREASE PRODUCTIVITY THROUGH AUTOMATION
  - MEET OSHA AND EPA REGULATIONS
  - PREPARE FOR EMERGENCY

* PROBLEM: NO ROBOTICS IN CURRENT U.S. SHIPYARDS
  - AUTOMATION LAG IN U.S. SHIPBUILDING
  - FEW OF A KIND
  - NEED ADAPTABILITY AND MOBILITY

* METHOD OF SOLUTION
  - GOVERNMENT HELP; INCENTIVES
  - EFFICIENT PROGRAMMING
  - SENSOR GUIDANCE AND COMPUTER CONTROL OF ROBOTS AND SEMIAUTONOMOUS TELEOPERATORS

SRI STUDY ON ADVANCED AUTOMATION FOR SHIPBUILDING

* SUPPORT

  NAVY'S MANUFACTURING TECHNOLOGY PROGRAM UNDER MANAGEMENT OF THE NAVAL MATERIAL COMMAND

* OBJECTIVES

  (1) STUDY EXISTING SHIPBUILDING TASKS

  (2) PRIORITIZE TASKS FOR ROBOTIC IMPLEMENTATION

  (3) CONCEPTUALLY DESIGN ROBOTIC SYSTEMS FOR THESE TASKS AND IDENTIFY R&D ISSUES

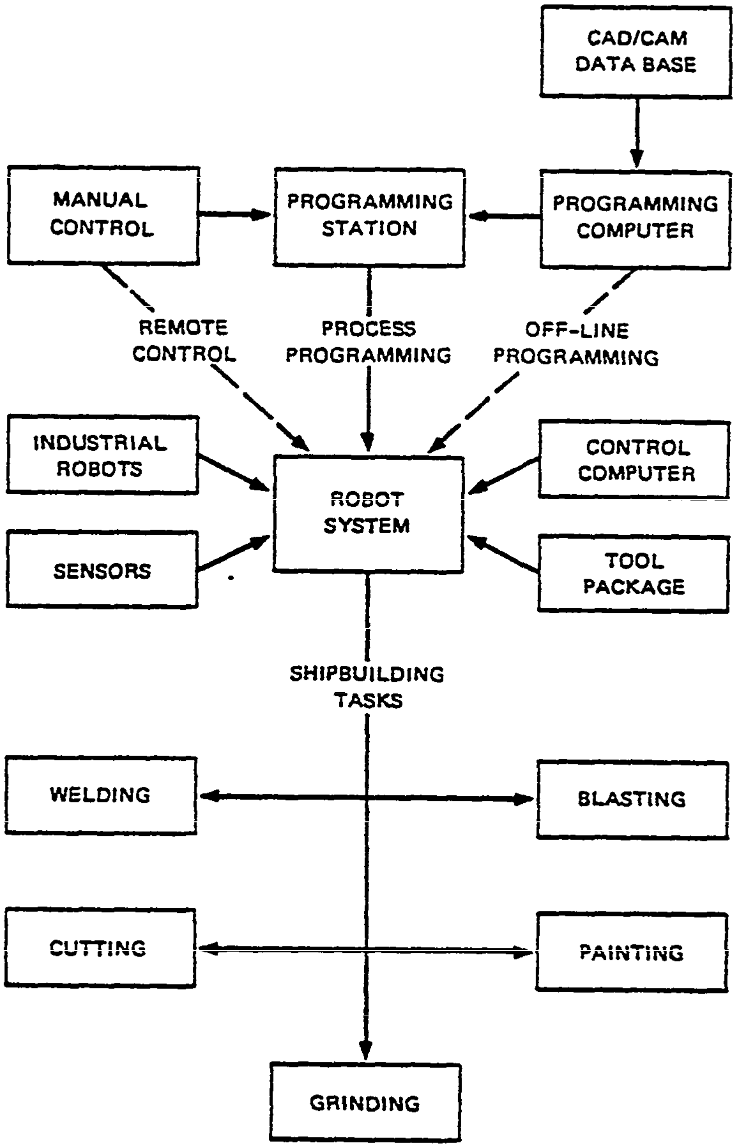
* METHODS

  (1) LITERATURE SURVEY; VISITS TO FOUR SHIPYARDS

  (2) TECHNOECONOMIC ANALYSIS; WORKING ENVIRONMENTS

  (3) APPLY COMMERCIAL ROBOTIC TECHNOLOGY; EXTEND ROBOTIC R&D

* FINAL REPORT



ORGANIZATION OF A ROBOT SYSTEM IN SHIPBUILDING

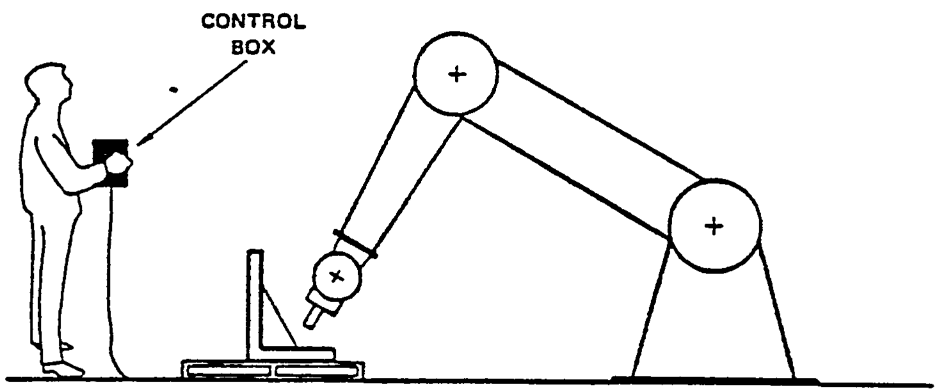
ROBOT PROGRAMMING METHODS

(1) MANUALLY PROGRAMMING THE ROBOT

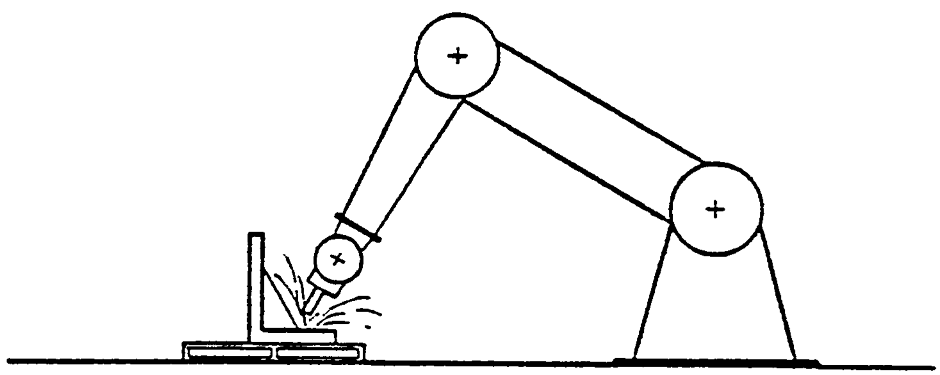
* USING A CONTROL UNIT
  - GUN (JOINT COORDINATES)
  - BOX (CARTESIAN COORDINATES)
  - JOYSTICKS (CARTESIAN COORDINATES)
  - REPLICA (SCALED DOWN)
* LEADING A ROBOT BY ITS HAND

(2) MANUALLY PROGRAMMING A MEASUREMENT ARM

(3) OFF-LINE PROGRAMMING USING CAD/CAMDATA BASE

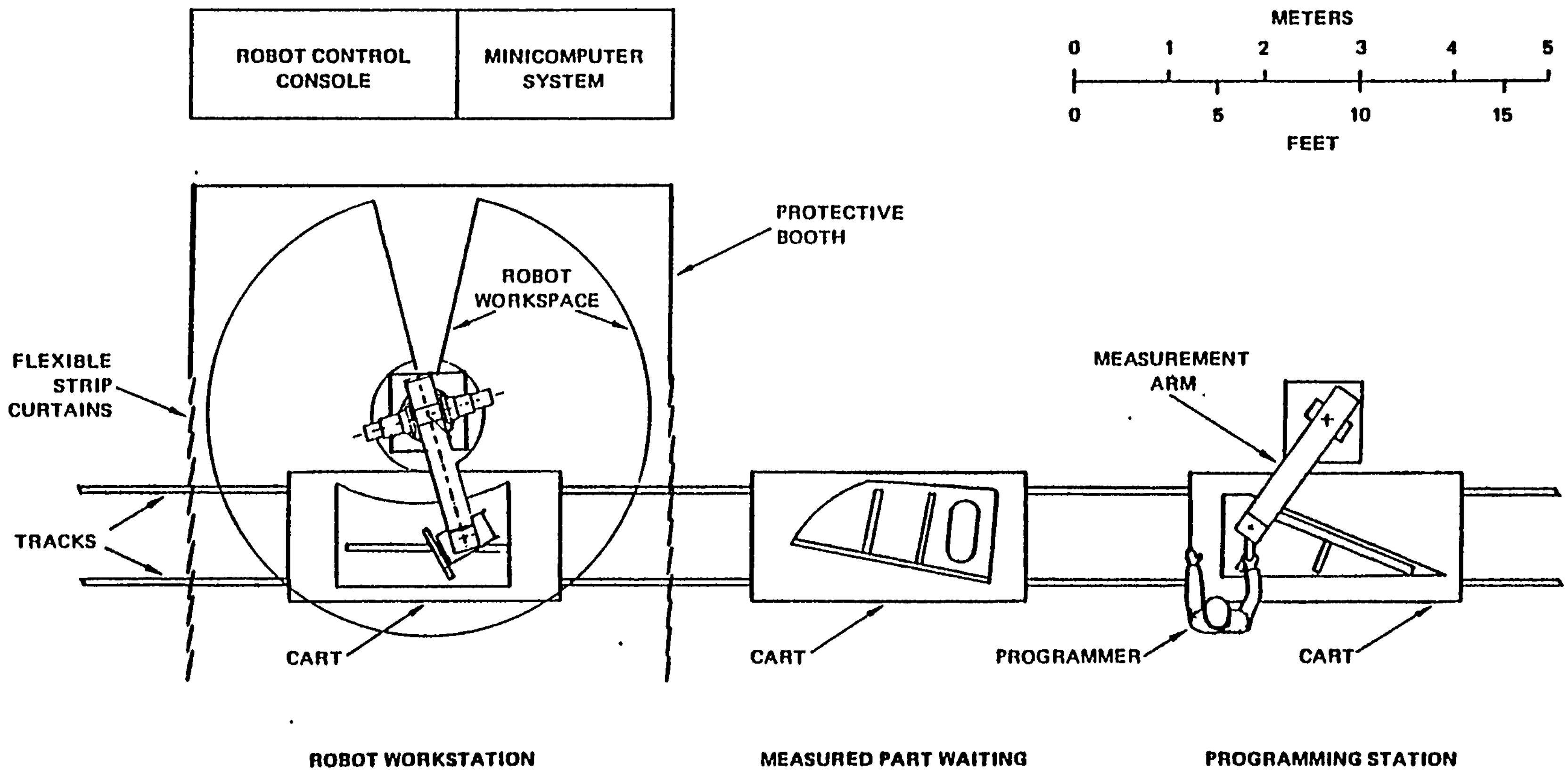


(a) PROGRAMMING A ROBOT FOR PART PROCESSING



(b) ROBOT PERFORMING WORK (SAME STATION)

MANUAL PROGRAMMING USING A ROBOT



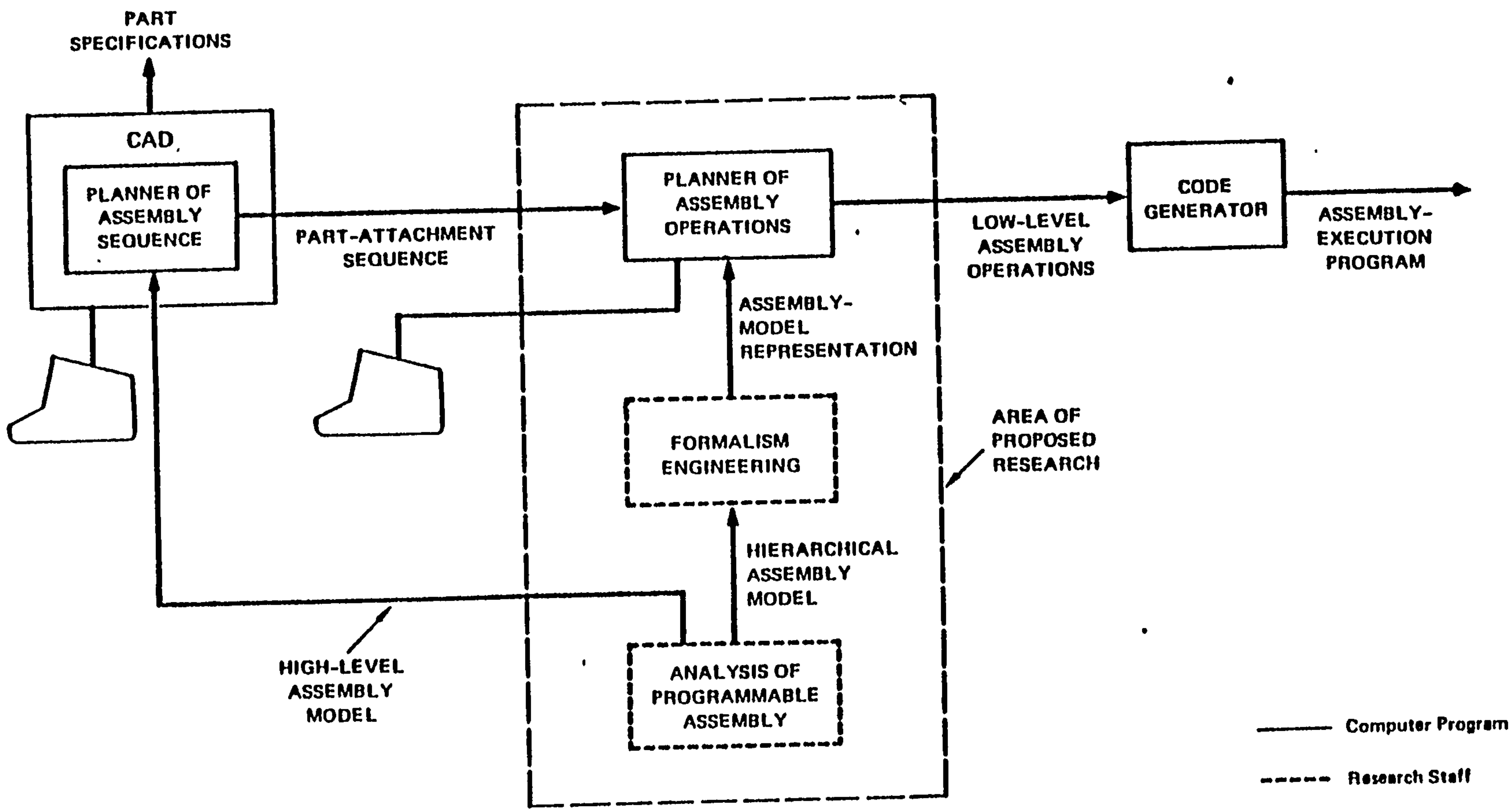
USING A MEASUREMENT ARM TO PROGRAM A ROBOT

ROBOT PROGRAMMING R&D ISSUES

* USE OF SENSORS TO LOCATE AND INSPECT WORKPIECES

* MODELING WORKPIECES AND ROBOTIC SYSTEMS AND PROCESSES IN SHIPBUILDING

* DEVELOPING COMPUTER EXPERT SYSTEMS FOR SHIPBUILDING
  - INTERACTIVE DESIGN OF WORKPIECES AND ASSEMBLY SEQUENCE
  - INTERACTIVE PLANNING OF MATERIAL HANDLING, INSPECTION AND ASSEMBLY PROCESSES
  - REPRESENTATION OF SHIPBUILDING MODEL IN THE COMPUTER
  - GENERATION OF MEASUREMENT AND EXECUTION PROGRAMS



MODELING AND COMPUTER-AIDED PLANNING OF PROGRAMMABLE ASSEMBLY

ROBOTIC WELDING INCENTIVES

* MOST LABOR INTENSIVE IN SHIPBUILDING (15%)
  - STRUCTURES (9%); PARTIALLY SEMIAUTOMATED (CARTS; OTHERS)
  - PIPES (4%); FAIRLY SEMIAUTOMATED

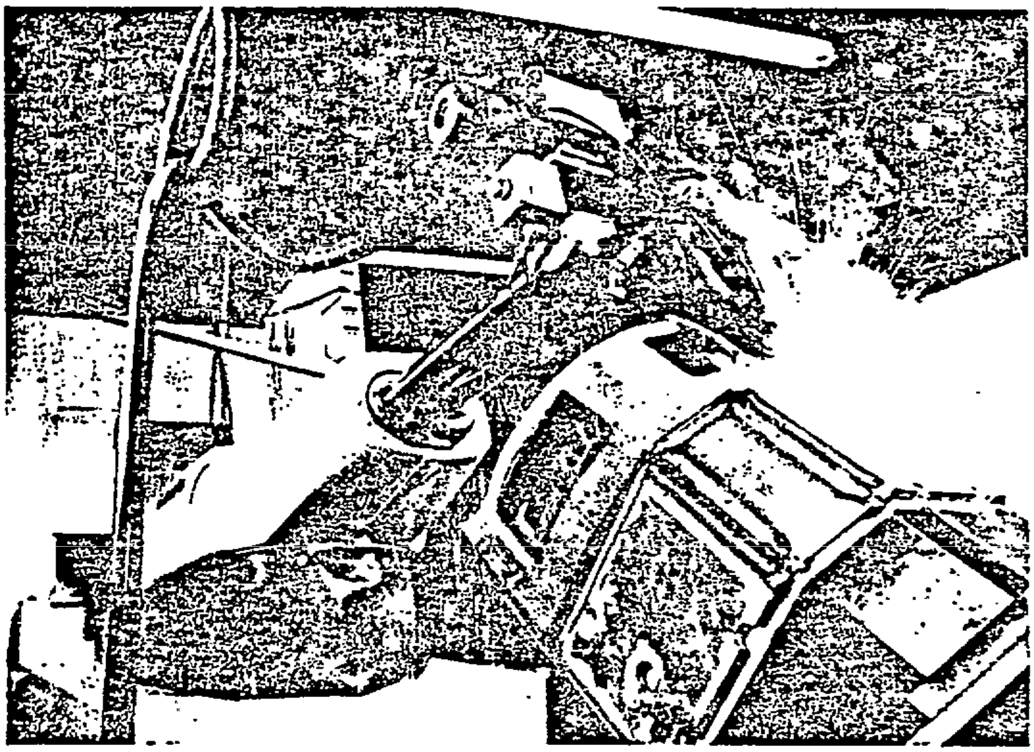
* INCENTIVES FOR ROBOTIC ARC WELDING
  - STRUCTURES
  - PRODUCTIVITY INCREASE (DEPOSITION RATE X2; DUTY CYCLE X3)

EXISTING ARC-WELDING AUTOMATION

* INDUSTRIAL ROBOTS
  - PRIMARILY IN JAPAN
  - REQUIRE WORKPIECE INDEXING

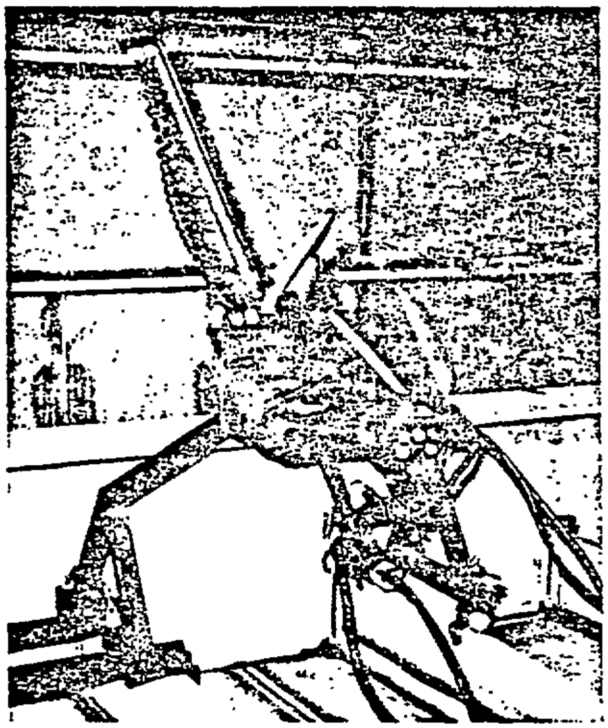
* PORTABLE STRUCTURE WELDERS
  - CARTS
  - OTHERS

* PIPE WELDERS



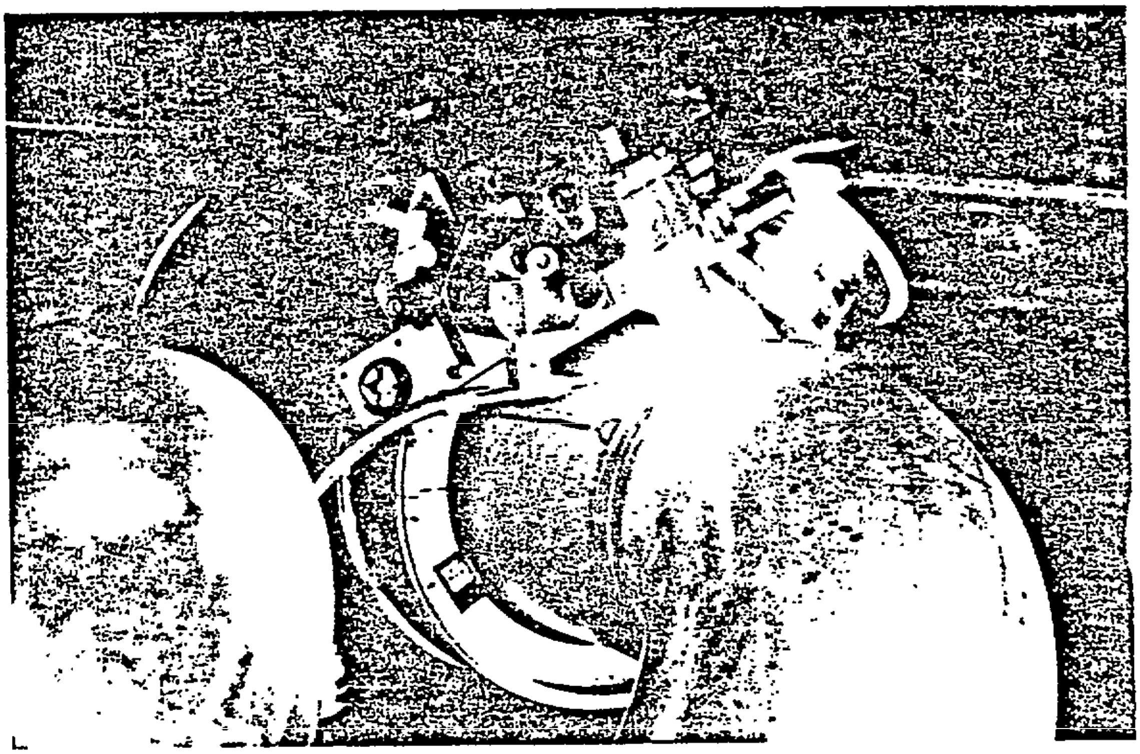
SOURCE: Unimation, Inc.

UNIMATE SERIES 2000 ROBOT WELDING A HOUSING



SOURCE: Unimation, Inc.

UNIMATION'S APPRENTICE ARM FOR SHIP WELDING



SOURCE: Dimetrics, Inc.

SEMIAUTOMATIC ORBITAL PIPE WELDER

ROBOTIC ARC-WELDING R&D ISSUES

* ADAPTIVE CONTROL OF WELDING
  - SENSING JOINT POSITION AND GAP AHEAD OF ARC
  - SENSING PUDDLE AND TEMPERATURE DISTRIBUTION
  - USING SENSORY DATA TO SERVO TORCH AND WELDING PARAMETERS

* INSPECTION OF WELD QUALITY
  - SURFACE
  - INTERIOR

* MOBILITY OF WELDING ROBOTS
  - IN CRAMPED ASSEMBLIES
  - ABOARD SHIP

SENSORS FOR ROBOTIC ARC WELDING

* CONTACT SENSOR -- JOINT POSITION
  - WHEELS (ATTACHED TO WELDING CARTS)
  - ELECTROMECHANICAL PROBES

* EDDY-CURRENT SENSOR -- FILLET JOINT POSITION

* ARC RESISTANCE SENSOR -- JOINT POSITION

* VISUAL SENSOR -- JOINT POSITION AND GAP; PUDDLE; WELD SURFACE

* ACOUSTIC SENSOR -- WELD INTERIOR

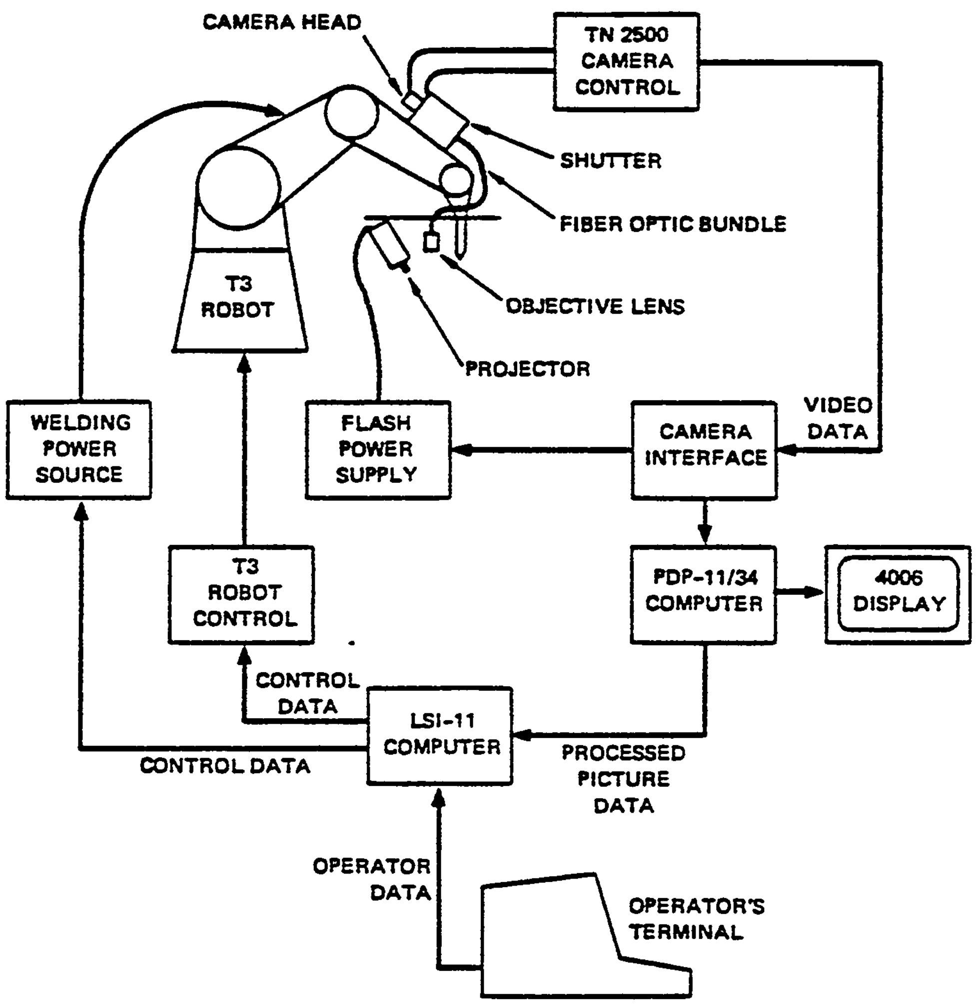
PROJECTS ON AUTOMATIC WELDING WITH VISION

* NASA'S MARSHALL SPACE FLIGHT CENTER
  - INCANDESCENT LIGHT PROJECTED ON BEVELED BUTT JOINT
  - REFLECTED IMAGE USED TO SERVO TORCH

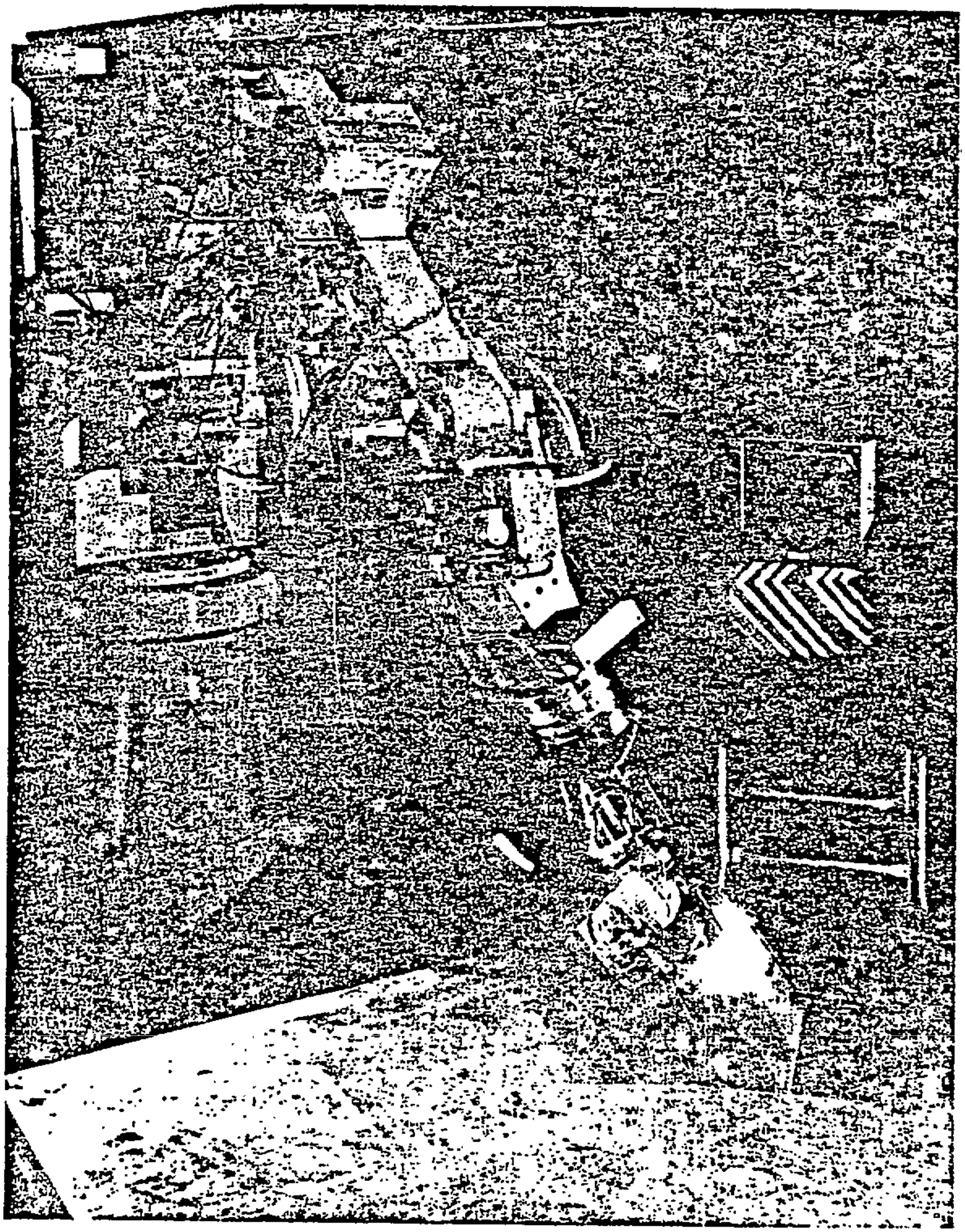
* KAWASAKI HEAVY INDUSTRIES
  - PLANAR LASER LIGHT PROJECTED ACROSS JOINT
  - IMAGE OF INTERSECTION LINE USED TO SERVO UNIMATE

* MITUSI SHIPBUILDING
  - XENON LIGHT PROJECTED ON FILLET JOINT AT 65 TO HORIZONTAL
  - INTENSITY CHANGE USED TO SERVO TORCH

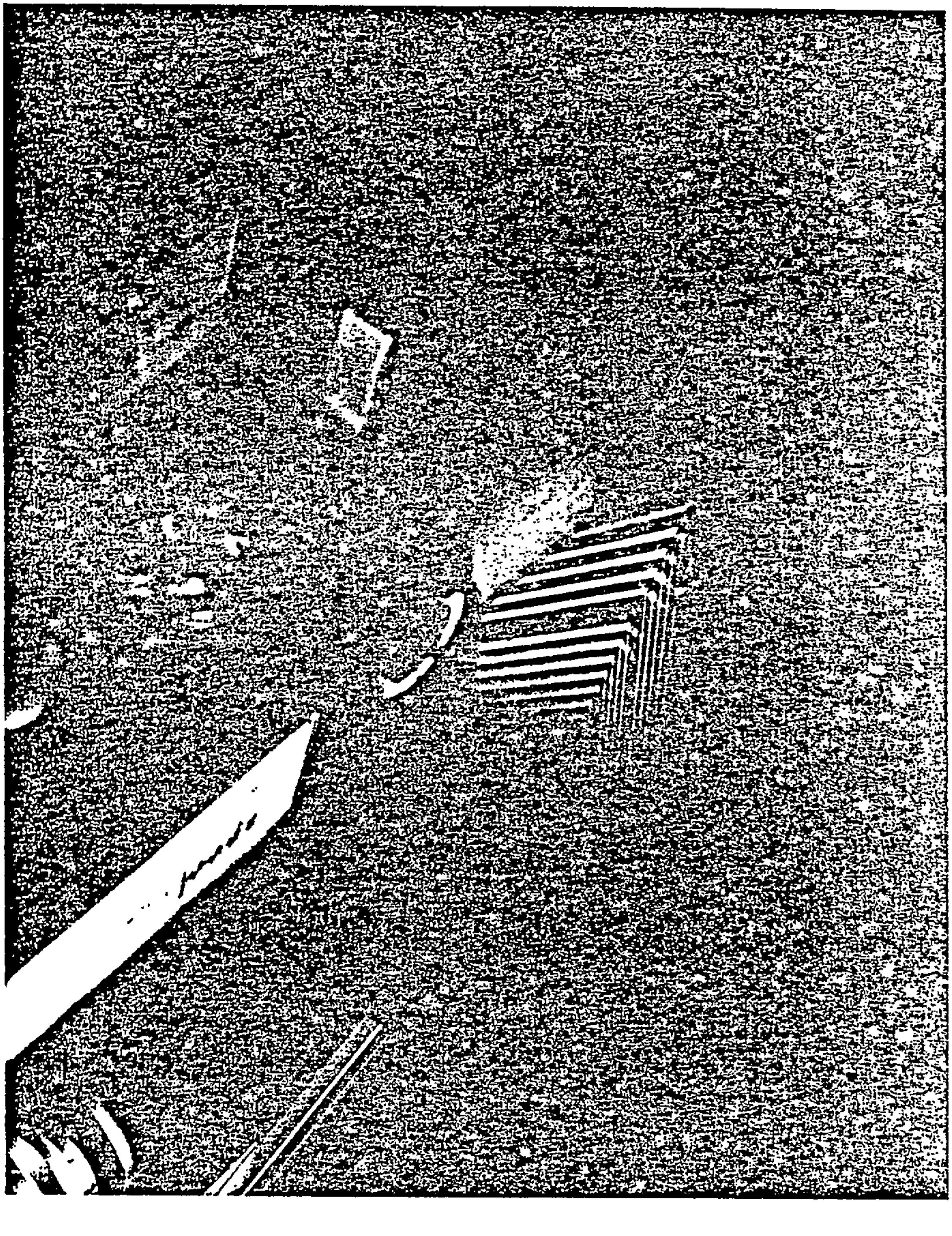
* SRI

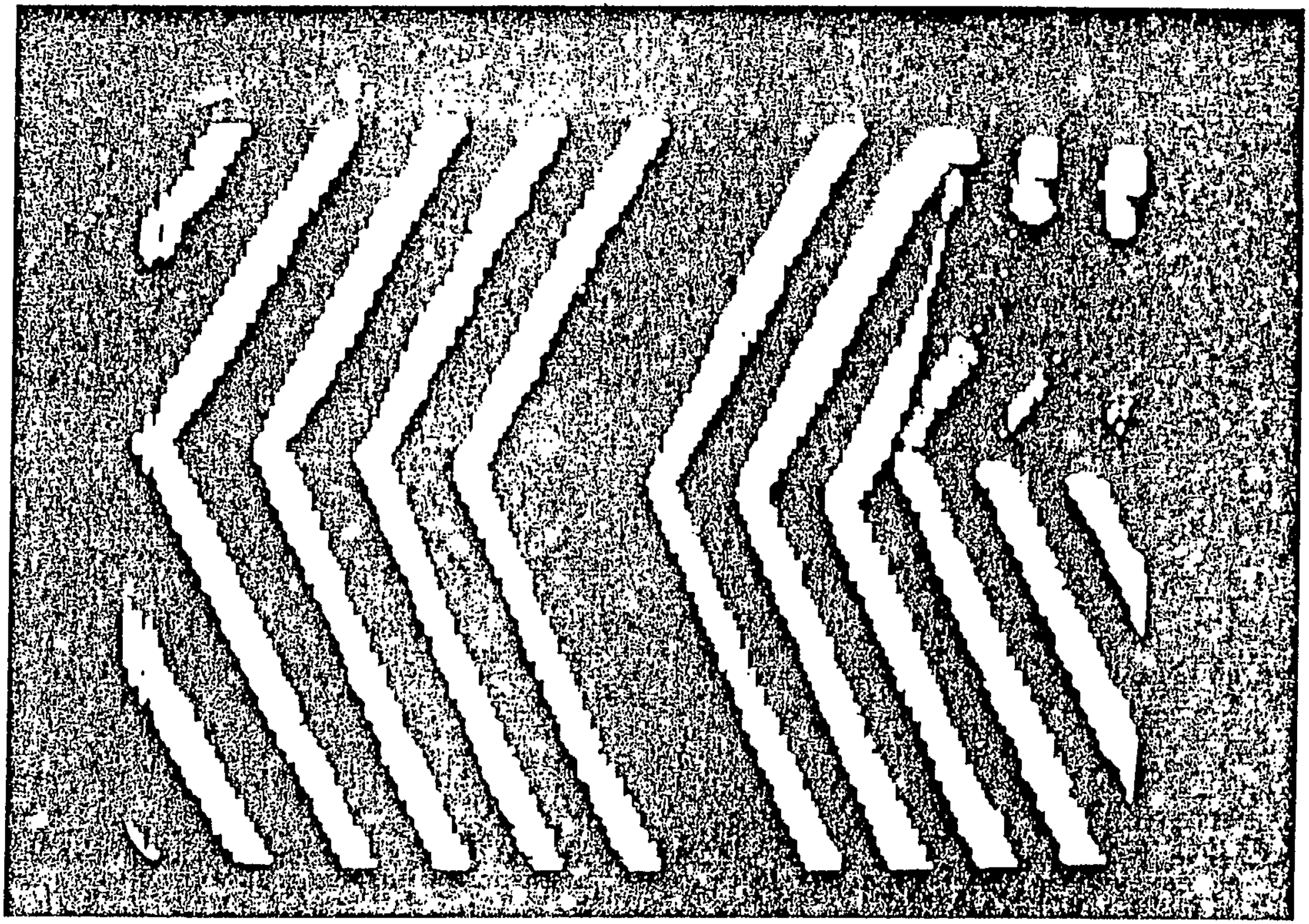


BLOCK DIAGRAM OF VISUALLY GUIDED ROBOT
ARC-WELDING SYSTEM

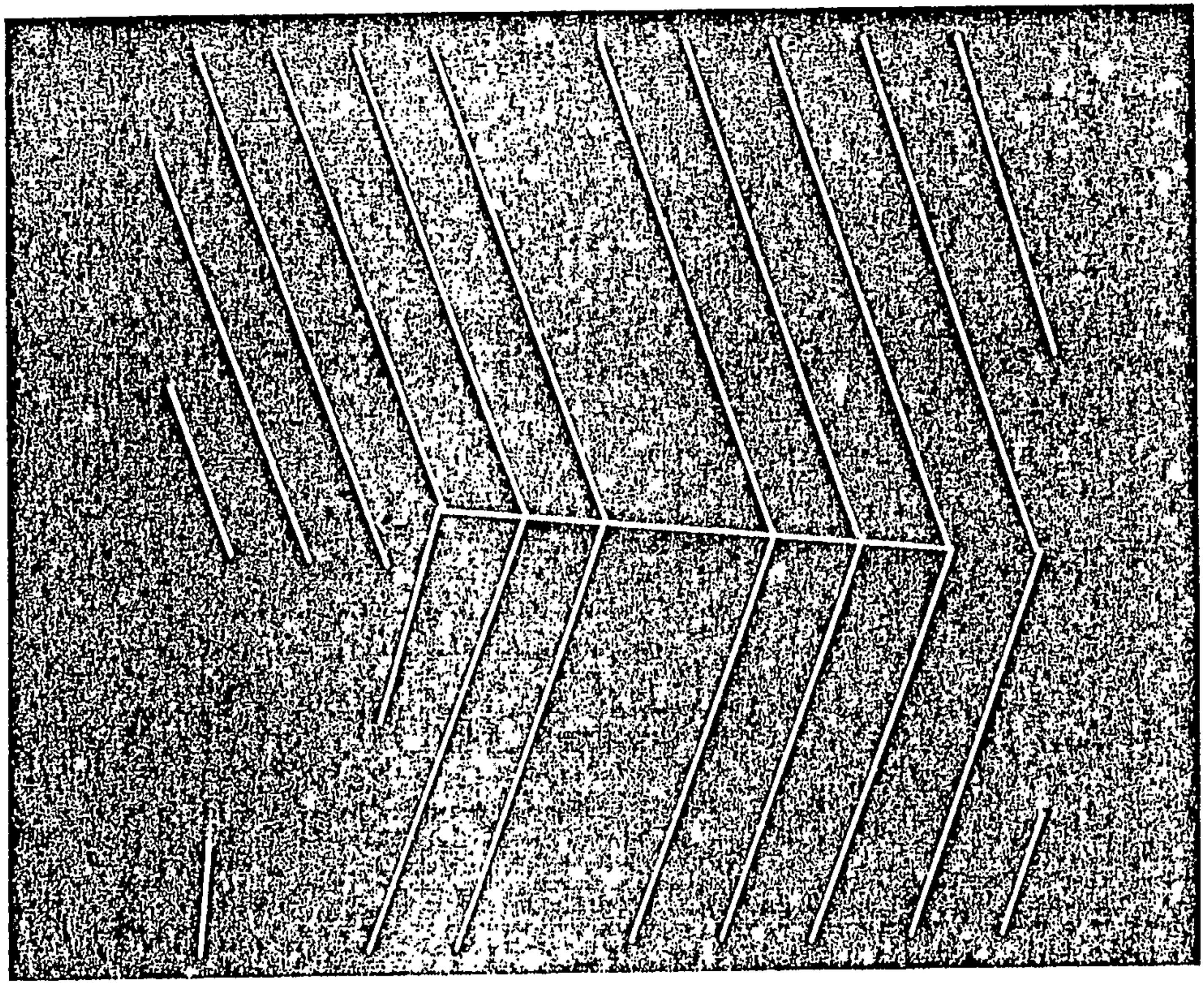


EXPERIMENTAL ROBOT ARC-WELDING SYSTEM

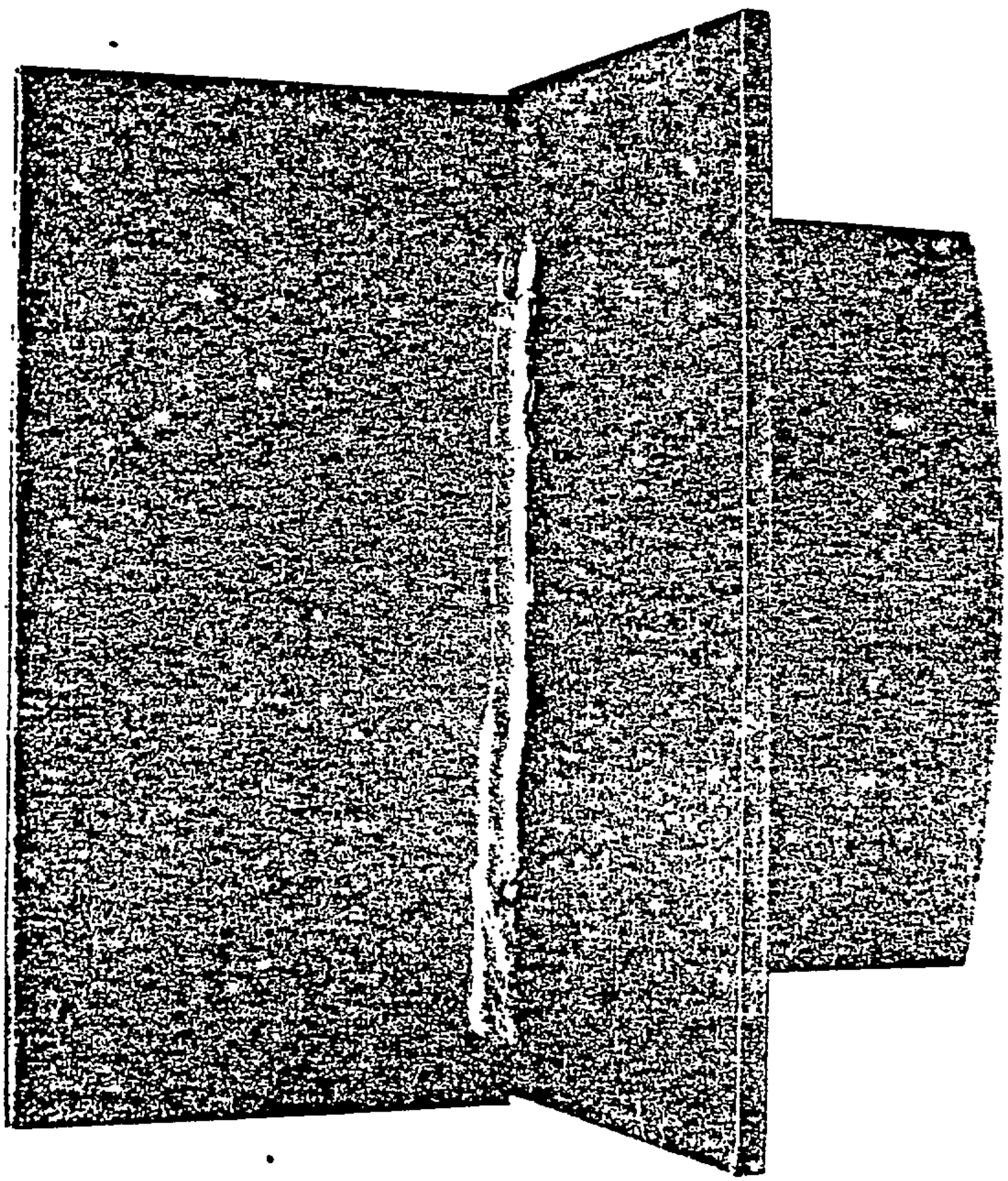




BINARY IMAGE OF FILLET JOINT



FILLET JOINT PATH



AVAILABILITY OF
ROBOTIC SYSTEMS COMPONENTS

by

Mortimer J. Sullivan

Manager of Sales

Unimation® Inc.

Danbury, Connecticut

Robotics in Shipbuilding Workshop
October 15, 1981
R.M.S. Queen Mary
Long Beach, California

Unimation Inc.

ABSTRACT

Availability of

Robotic Systems Components

The paper briefly deals with a look at the use of robots in arc welding, propeller grinding, painting, abrasive blasting, burning, and grinding of welds in ship construction.

Good afternoon gentlemen. I am more than pleased to be here to have the opportunity to discuss with you robotic systems in the shipbuilding industry.

Let us first ask the question what is a robotic system? In the shipbuilding industry, as I see it now, we could use robotic systems for (1) arc welding (2) grinding of propellers (3) painting (4) abra-siveblasting (5) burning and (6) grinding of welds.

Taking Each system step by Step for Shipbuilding

What makes up each system and is it practical? Is is available? If not available, is it a short (one year) development or a long range development?

Arc Welding Systems

These systems require a robot, a power supply, and a wire feeder.

Presently the submerged arc, semiautomatic equipment and straight line automatic equipment does a very decent welding job for the long, straight welds. Where you need help is the nonstraight, out-of-position, curved, compound curved and woven weld seams.

Have you ever seen a straight, long weld in a submarine? Everything is tuned or compound curved with many multipass and woven seams. There is available today, off-the-shelf, a practical portable arc welding robot for certain areas of ship construction.

Letts take for example a stiffner or intercostal plate of which there are thousands in submarine construction and probably just as many in warship construction. It is a welded plate between "T" sections of stringers *or* longitudinals to prevent them from tripping. With the tolerances of ship construction, these plates are individually cut, fit, and welded. It is a time consuming process. If we, however, use an available robot **called the APPRENTICE® robot you can reduce your welding** time. With the APPRENTICE robot you would cut and fit the plate, and then trace the path you desire the robot to weld. Incidentally the robot can do a triple pass weld although rolled in one seam. It is important to note that with this robot, teaching time for the path is completely independent of the welding time. In another words, you may teach a weld in three minutes which might take as much as eighteen minutes to accomplish. Again, there is no relationship between teaching time and the welding time. Teaching is fast, welding can be very slow. Let me show you a short movie, and then we shall continue because as you well know, a picture is worth a thousand words.

UNIMATION® Apprentice Film

Now you see how the robot works.

This is off-the-shelf robotic automation presently used in heavy metal fabricating plants in the U.S. and abroad.

I might add as an aside that the portion of the movie you have just seen showing a robot welding a robot was taken by an outside movie maker who was later arrested as a KGB agent. One would assume that the Russians are interested in robotics for heavy welding.

Returning to the case of the intercostal plate, we have been asked if it would be possible to take off the motions of the APPRENTICE robot while tracing an area where a plate is to be installed. This x-y data would be fed to another APPRENDICE robot or another device fitted with a cutting torch. The plate would be cut and the program for its weld, accomplished at one time. Obviously, if the same path is traced, the cutting of the plate and the fitting of the plate would be far more accurate. This would produce a better quality of fit and would increase productivity.

This would be applied research and development, but it seems to be a very feasible approach; and I would consider this a short-term development. A prototype could be tested within one year after receiving a go ahead. Everything *is* within the present state of the art.

Robotic Propeller Gringing System Requirements:

One or more continuous path robots with large memory, tactile sensing, large reach, firm fixed foundation, and necessary grinding equipment.

In this system we are obviously talking of a fixed foundation installation where both the robot and the propeller will be held in constant fixed relationships. There is an extensive amount of grinding and polishing done on marine propellers which require a high labor input. Since the program the robot follows may easily be changed, the differences between propellers of various sizes and shapes can be quickly accommodated. Even if the robot were only used for rough finishing, it would be more consistent than a human. Since it can hold heavier grinding equipment than can a man, the robot could finish the job faster.

Robotic propeller grinding systems are within the state of the art today for at least rough grinding. The further development of tactile systems will probably allow for finish grinding if not in fact final polishing.

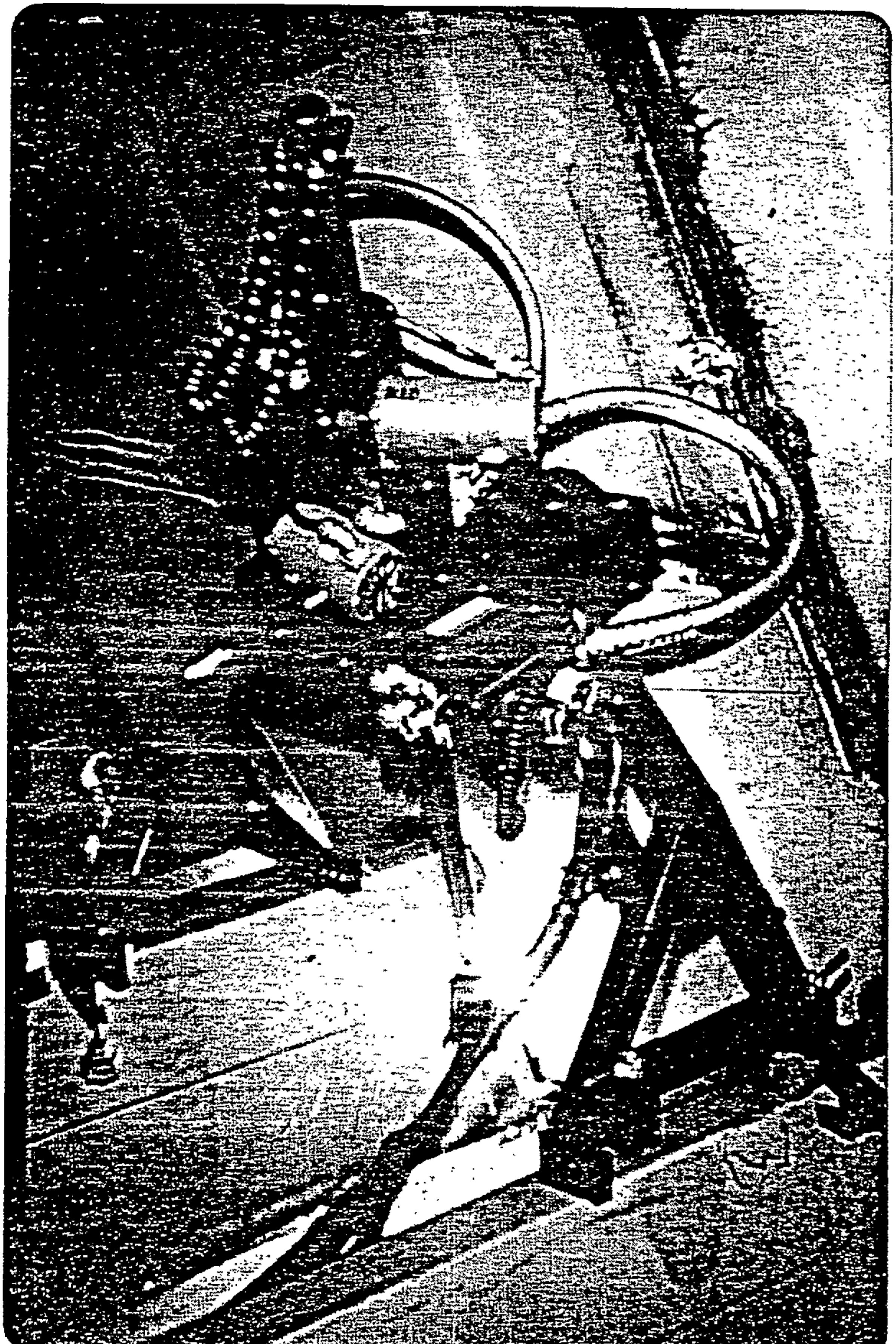
Painting/Abrasive Blasting

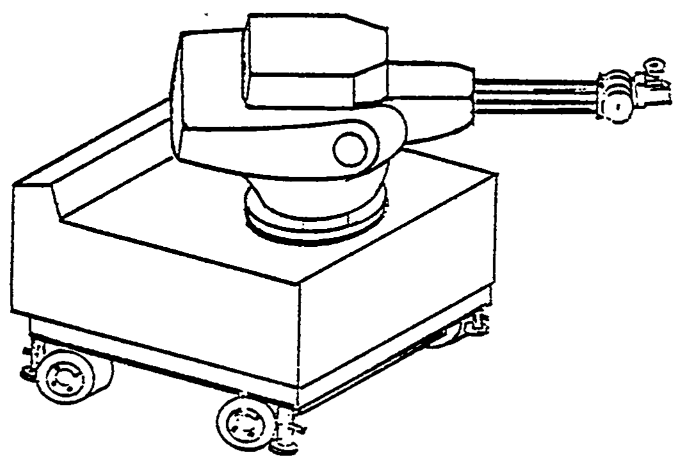
I group these two categories as one since the robotic components are similar, though less sensitive in abrasive blasting.

Requirements: A large reach robot, portable, continuous path for heavy loads, easily and quickly programmed. Associated painting or abrasive blasting equipment, and the necessary consumables of paint or grit. Such a painting installation should not require a high degree of accuracy, say ± forty thousandths, as one usually expects from a robot. It should however have enough accuracy and straight line movement characteristics to present a visually acceptable painting border. In abrasive blasting less accuracy should be acceptable.

I can visualize this as a wheel. mounted robot with jacks to fimily anchor it to the ground, or a stand where it will do a portion of the job. It would then be shifted to another location to complete that section. Working alone, or with other robots, the entire surface could be covered.

Obviously the robot would have to be unitized with its hydraulic power pack (or electric motor) and control console in one piece. It should also have pressurized controls and mechanical linkages *to* preclude the entrance of paint or grit. Exposed surfaces should be covered with bellows on moving arms and joints.





ARTIST'S CONCEPTION OF UNITIZED WHEEL MOUNTED PORTABLE ROBOT

I see the greatest problem in such an installation as the programming method which should be fast. The placement of the robot at predetermined spots on a similar class of vessels could be worked out in advance. Once the program was established, it could be fed into the robots memory each time it is moved from place *to* place, from ship to ship.

The mounting of the robot on a pneumatic tired truck or trailer, I believe, does not present any problem with today's unitized robots. It would be logical to have a marker fore and aft on the vehicle so that accurate placement could be accomplished quickly.

I might add here that the U.S. Army is looking into portable, trailer mounted robots for projectile loading from pallets to armament in the field.

Burning

Requirements: A robot with continuous path capability, long reach, fixed installation, a burning torch, and associated equipment.

One of the problems in welding heavy fabrications with robots is the poor cut and fit of the parts. If the parts are cut by a robot to ± .040, then the robot's brother should be able to weld these fabrications with less problems. Compatibility of equipment in this *case* will aid in the manufacturing process.

Also, the integration of CAD/CAM equipment here could greatly enhance productivity. Cutting could be done directly from computer inputs. Welding programs could be fed into the robotic welder not only for greater productivity, but also for higher quality.

I believe a portion of this system, less the CAD/CAM, is presently within the state of the art. The addition of CAD/CAM depends on the amount of money management wishes to invest in a permanent installation. I would suggest that CAD/CAll is a few years down the line for this robotic system.

Grinding of Welds

Requirements: Continuous path, quickly programmed, force feedback control system, tactile sensing, long reach robot, portable and unitized, or fixed location, power grinding or wire brushing equipment.

We presently have robots, such *as* the ASEA, which incorporate some Of these features. The ASEA robots are nonunitized, fixed location machines and can be programmed to grind production type, identical., weldments. Here I see the problem as being twofold.

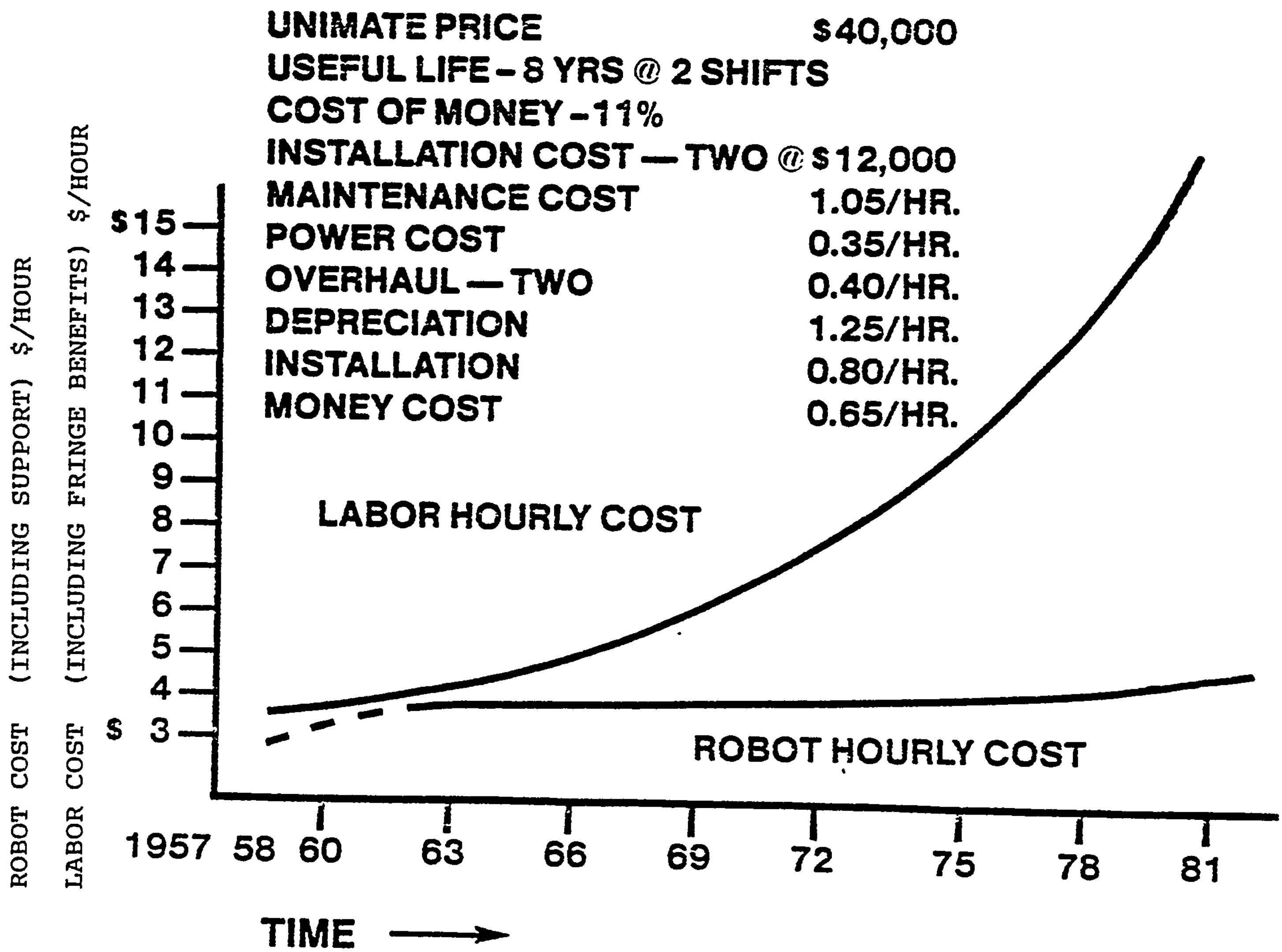
First, quick programming. It is not really available anywhere. Large production, identical runs can make the programming time small in relation to the overall run, but the programming by itself is time consuming.

Second, portability. It would probably cost less *to* move the robot to the fabrication than the fabrication to the robot in ship construction. Again, positioning of the robot accurately when moved from location to location is a necessity.

These grinding systems, I feel, are partially available today, but more applied research must be done to allow for faster programming and portability.

In summation, there are robotic systems available today for some shipyard applications. Others are not far down the road, but it is you, the purchaser, not me, the manufacturer, who will determine the length of that road. You have to be willing *to* invest in productivity, and America's future industrial base.

ROBOT COST ASSUMPTIONS AS OF 1981



HISTORY OF LABOR COST AND HISTORY OF UNIMATE ROBOT COST IN THE AUTOMOTIVE INDUSTRY

CLOSING SPEECH

James W. Tweeddale
Director, Productivity Management
Office of the Assistant Secretary
of the Navy (MRA&L)
Washington, D.C.

I really have a question, and I would like to ask the question and then think retrospectively on the question with a few stories; and the question is: Where do we go from here as an industry? Nowmy stories are not directly related but yet they are in proper context. I work at Washington, D.C. in Crystal City and those of you who have visited there know that area,particularly in January & February,is quite cold. This past February I was in my fourth floor office looking out early in the morning at an ice covered sidewalk and roadway, and I noticed an.elderly lady with a white cane, obviously impaired vision, making her way toward a corner and ultimately, hopefully, across the street. What this lady did not see was vehicular movement toward the corner, and there was a gray Navy van making its way toward the corner about the time that she was making her way there. There was some construction in the area so I understood by my visual perception that she was having a hard time hearing that van approach the corner. As she stepped down off the curb, it was about the time that the van hit the' corner and of course it hit her arm, she skidded and she fell down. Now I saw an accident emerging, I anticipated the accident probably thirty-five or forty seconds before it actually occurred. Several people who were at the sidewalk level ran out to meet the lady and helped her to her feet and I was quite pleased that she was able to walk away from the corner, though visibly shaken, and my question was: did I have a problem, as I witnessed the unfolding of an accident that ' could have been more serious than it was. Now as you think about that, did have a problem as I stood there in my fourth story office, no way for me to get to ground level in order to help her, though I would have certainly, had I had resources to get there. I would contend that I didn't have a problem. Let me say this, I thought about the problem as I looked down I saw what was happening and I began to internalize the problem and I felt pretty bad about it, but I didn't have a problem. I did not have access nor ability to influence events to regress the problem and therefore I didn't have one. Though I felt bad about it, I wasn't able to help that elderly woman.

My second story deals with the fact as I was out this morning, as I have done for the past three or four mornings, running. There were some other folks out there running as well and I think I might have seen one or two of you as wel1. Now for the past eight or ten - maybe twelve-years I've been running because I like it and about eight years ago I had, as a figment of my imagination, that I could-win the Boston Marathon; I trained for the Boston Marathon. About seven years ago I qualified and I entered the Boston Marathon. It was a time when Frank Shorter was really in his prime, and I went to Boston all hyped up figuring that, you know, well who's Shorter. I can recall that day very, very clearly. Within my mind, I had an ideal state for myself and part of that ideal state was that I wanted (amongst other things that I felt I've accomplished in life), to win the Boston Marathon. I had also gone through a present-state analysis where I understood, and I felt really, I guess-through a process of physical condition and psychological hyping I could win that marathon. So I went, of course, and participated in that event. One of the competitors was a seventy year-old gentlemen that was obviously in excellent condition - especially for his age. Of course amongst other competitors was the likes of Frank Shorter. Well I can recall the first two or three miles I stayed right up with the pack, but you know in the emotional frenzy of the event, I realized after about mile four that I could not sustain the pace, and though I tried to push myself, about mile six I began to realize that I had better slow down if I was to finish at all. So I slowed down. And for the next twelve or fourteen miles it seemed that the whole world passed me by; hundreds and hundreds of runners passed me by. In the process I began to redefine my ideal state, and that was winning the Boston Marathon may not be in the cards for me. Especially, you know, at mile twenty-one. These guys that designed Boston are sadistic or maybe by coincidence at mile twenty-one they have a hill which they affectionately call Heartbreak Hill. Anyway it was there at Heartbreak Hill that I metmy Waterloo. After, I would say, several hundred people had passed me (and I know that I looked like someone that the cat had just drug in) I realized that at the top of the hill were some people and they started clapping. I thought they were applauding for me, you know, and well-that gave me a little glimmer of hope; but as I got half-way up that hill this'old seventy year-old gentleman passed me by and it was he they were applauding. By the time that I finished Boston, Frank Shorter had already showered and was in his street clothes. well, I must say that I did redefine my ideal state.

Now I say to you as managers in the industrial world of work, we must go through a present state analysis. I think there's been some of the going on - especially in the workshop sessions of the past day or two. People have been looking introspectively at themselves and trying to determine where they wanted to be in the future. Step one in the process of industrial growth starts with honest, no nonsense, (as tough as it is) present-state analysis and is an essential part of corporate movement. We've got to be able to understand and see ourselves as we are though it hurts an awful lot. I can recall in Machiavelli's little book, "The prince" (that I read a good number of years ago) Machiavelli addressed the issue of the management of change.

What he says is that the change agent has for adversaries all those that have done wel'1 under the old system, and he has for defenders - only lukewarm defenders - all those that may do well under the new. We have a built-in base of adversarial forces in our industrial world of work, especially if I am talking about introducing technological change. But I must say that this (Workshop) leading and others like it that are popping up around are I think, providing a vivid testimony to managers that technology has a central role in the process of bringing the corporate structure toward the point that it needs to be in the future. Now our ability to properly implement this change-to address technology at appropriate thresholds of the organizations-is contingent upon us.

I can recall that fairly recently I went up to visit some folks at Ford Maway, New Jersey. Those of you that have been reading the papers over the past year or two know Ford went out of business June of last year in Maway. They closed down their plants laid off 5,000 employees; they were out of business. Ford Maway is no longer a viable corporate entity. What really struckme about that failure is that fifty miles up the river from Ford Maway is GM Tarrytown where they're producing X-body cars like they're going out of style. I spoke to one of the corporate managers at Ford about why only fifty miles from GM Tarrytown, Ford, using the same people having access to the same technology, dealing with the same consumer markets , could fail while GM prospered. The problem, he said, was poor quality. Poor product quality, and he basically said that he had misread his organization. The issue was present-state analysis. He didn't understand where he was and by the time he did, it was too late to make meaningful change.

Now I say that the only key thing is as an industrial comnunity, as a shipbuilding industry, that keeps us from being where we need to be in the future is guts in management. That's all it takes: enlighted management.

APPENDIX D

<u>CMT-3 ROBOT PROJECT</u>

<u>MARAD PROJECT NO. MA-80-SAC-01041, TASK NO. 7-2</u>

<u>DEMONSTRATION</u>

CMT-3 ROBOT PROJECT

MARAD PROJECT NO. MA-80-SAC-01041 , TASK NO. 7-2

Equipment Procurement

1. The equipment selected for this project included:
   - a. Cincinnati-Milacron T-3 6 axis computer-controlled industrial robot with associated hydraulic power supply, electricl power unit and computer control console;
   - b. Hobart RC 650 RVS power supply with Hobart Mega Con III digital wire feed system and Bernard #3500 water cooler circulator; and
   - c. Aronson Model 60CS 6000 1b. robotic welding positioner with a 1 rpm constant speed rotation and 135° Tilt (35 sec.).

Todd has purchased all equipment except the CMT-3 robot for which this sub-contract pays the first year rental. Any other add-on, support or material handling equipment is the responsibility of Todd.

2. Equipment was shipped in several lots, with the last being received in late July. It was all stored in a bonded warehouse until the complete system was available and the site prepared for installation. This was done to assure that both the vendor and Todd would be assured of the condition of the equipment at the time of installation.

Site Preparation & Installation

Site selection was given extensive consideration to assure that the CMT-3 could be conveniently available in the production flow, but located in such a position that it could be isolated and by-passed for evaluation and experimentation.

That proved to be in the corner of the Plate Shop where all utilities, material handling equipment and material access were available. Special precautions were taken to minimize contamination of the area and to prevent accidental damage to any of the components. A factory representative was on site to assist with the installation and checkout. A number of parts (PC Boards etc.) required replacement before and during start-up. Vendor cooperation was excellent. No significant difficulties were encountered in making the installation.

Operator & Maintenance Training

Todd's Manager of Welding Engineering, Welding General Foreman, one welder and one Maintenance Quarterman attended Operator's School and the latter Maintenance School at the Cincinnati-Milacron factory. In addition, the Vendor sent an instructor to Todd for one week of specialized training prior . to industry demonstration.

Demonstration to (Shipbuilding) Industry

A tilting antenna mechanism support bracket was selected for the demonstration because of it's complexity (requiring close tolerance access and both tilt and rotation of the positioner table) and requirement for both steel and aluminum structures on FFG. Several sample parts were welded in advance, and one completed in the presence of shipbuilders, vendors and robotic systems manufacturers. The demonstration established that ship sub assemblies can be welded by a robot; the questions that remain (as the subject of this project) are:

1. Will robots improve productivity; and
2. If so, what must be done to implement their use

Problem Areas

As of this time, no problem areas outside of the evaluation parameters have surfaced.

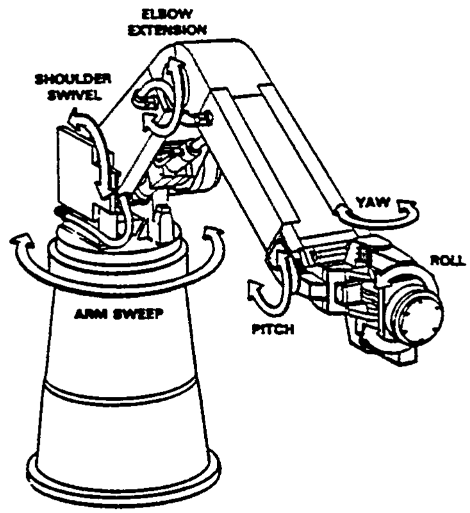
HE TOMORROW TOOL (T^3) Computer-Controlled Industrial Robot

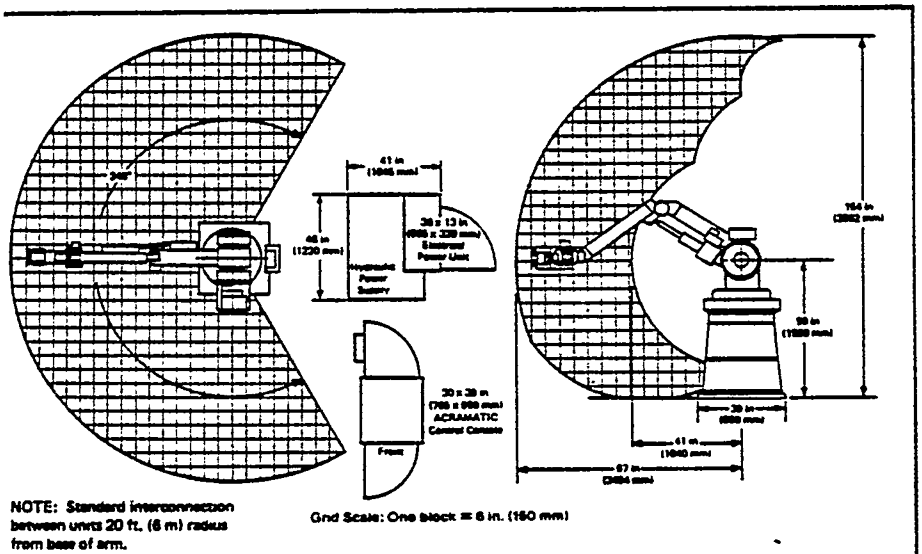
ıliable...smart...swift...strong...spacesaving...it offers ɔld application flexibility

:ecs for basic T^3

or space and net weight	
ndustrial Robot	9 sq. ft. (0.8 sqm) 5,000 lb (2267 kg)
Iraulic power supply	17 sq. ft. (1.5 sqm) 1,200 lb (544 kg)
ctrical power unit	3.4 sq. ft. (0.3 sqm) 700 lb (317 kg)
RAMATIC computer control	8.3 sq. ft. (0.8 sqm) 800 lb (365 kg)
ıd Capacity	
,d 10" (254 mm) from tool mounting plate	120 lbs (54 kg)
d at tool mounting plate, max. velocity	175 lbs (79 kg)
d at tool mounting plate, reduced velocity, epends on arm and wrist attitude*	300 lbs (136 kg)
ıitioning accuracy, axis drive	
,uracy to any programmed point	±0.050-in. (±1.27 mm)
/e for each of 6 axes	Direct, electrohydraulic
nted-arm motions, range, velocity	
ĸ. horizontal sweep	240°
ĸ. velocity of tool center point	50 ips (1270 mmps)
:h	190°
I	240°
/	180°
ver requirements	230/460 volts, 3 phase, 60 Hz, 22 KVA
tor	25 HP drive motor for hydraulic pump & tank
/ironmental temperature*	40 to 120°F (5 to 50°C)
IICOMPUTER memory capacity	700 points std.

ısult factory for special applications





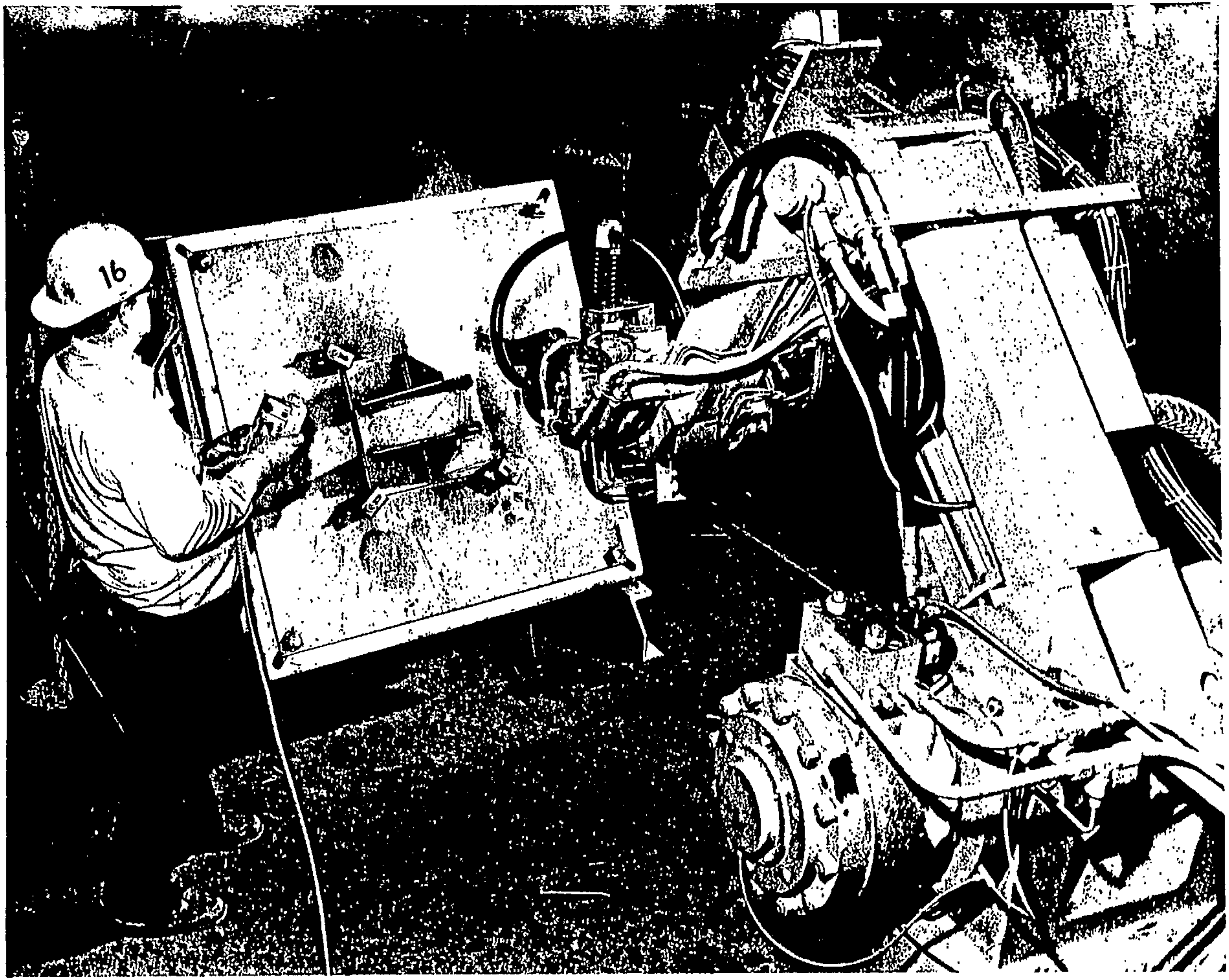
Basic range and floor space drawings

All illustrations and specifications contained in this literature are based on the latest product information available at the time of publication. The right is reserved to make changes at any time without notice in prices, materials, equipment, specifications, and models, and to discontinue models. In addition, all nominal dimensions are subject to an allowable variation of ±0.25-in. (6mm), unless otherwise specified..

WARNING: In order to clearly show details of this machine, some covers, shields, doors, and guards have either been removed or shown in an "open" position. Furthermore, operators are shown ONLY to indicate relative product size; they may be in positions which are NOT the normal or safe operating positions. Be sure that all protective devices are properly installed before operating this equipment.

CINCINNATI MILACRON

Cincinnati Ohio 45209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